Nanoplasmonics beyond the refractive index

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36th Meeting of the section
Atomic Molecular and Optical Physics (AMO)

Program and abstracts

October 9 and 10 2012
CongresHotel De Werelt
Lunteren
36th Meeting of the section
Atomic Molecular and Optical Physics (AMO)

Program and abstracts

Congres Hotel De Werelt
Lunteren

October 9 and 10 2012

Scientific Commitee:
Giel Berden • Martin van Exter • Ronald Hanson
Ronnie Hoekstra • Gert ’t Hooft • Femius Koenderink
Servaas Kokkelmans • Leo Meerts (chair) • Herman Offerhaus
Robert Spreeuw • Peter van der Straten • Wim Vassen • Caspar van der Wal

Program Committee:
Giel Berden • Caspar van der Wal

This meeting is organized under the auspices of the NNV-section Atomic, Molecular and Optical Physics, with financial support of the Dutch Science Foundation and the Foundation FOM.

Conference coordination:
Erna Gouwens (RU)
Tuesday 9 October 2012

10.00 Arrival, registration
10.40 Opening by the chair man of the section AMO Leo Meerts

chair: Ronnie Hoekstra

10.45 Jom Luiten (Coherence and Quantum Technology, Eindhoven University of Technology)
“Extreme beams for femtosecond electron imaging”

11.30 Short lectures: (Europa room)
O1 Rick van Bijnen (Coherence and Quantum Technology, Eindhoven University of Technology)
“Rydberg crystals and shaped ion bunches”
O2 A. Groot (Nanophotonics, Debye Institute for Nanomaterials, University of Utrecht)
“Faraday waves in a Bose-Einstein condensate”
O3 M. Nuñez Portela (KVI Atomic Physics, University of Groningen)
“Single ion Ra+ Spectroscopy for atomic parity violation”
O4 Julija Bagdonaite (Laser Centre, VU University Amsterdam)
“Search for a cosmologically varying proton-to-electron mass ratio from methanol”

12.30 Lunch

chair: Ronald Hanson

14.00 Markus Aspelmeyer (Quantum Optics, Quantum Nanophysics and Quantum Information, University of Vienna, Austria)
“Quantum Opto-Mechanics: a mechanical platform for quantum foundations and quantum information processing”

14.45 Short lectures: (Europa room)
O5 S. Cigdem Yorulmaz (LION Quantum Optics&Quantum Information, Leiden University)
“Spatially entangled 4-photon states from periodically poled potassium-titanyl-phosphate crystal”
O6 A. R. Onur (Zernike Institute for Advanced Materials, University of Groningen)
“Quantum optics with semiconductor spin ensembles”
Tuesday 9 October 2012

15.15 Poster Introduction – 1 minute per poster (P1 t/m P36)  
chair: Giel Berden

15.45 Coffee/tea break

16.15 Short lectures: (Europa room)
O7 G. Reitsma (KVI Atomic Physics, University of Groningen)  
“New fragmentation pathways in ion induced PAH dissociation”
O8 A. Petrignani (Leiden Observatory, Leiden University)  
“Infrared Multi-Photon Dissociation of highly stable PAH cations at FELICE”
O9 D. Marchenko (Molecular and Laser Physics, IMM Radboud University)  
“Development of the external cavity quantum cascade laser for spectroscopic applications”
O10 I. Barmes (Laser Centre, VU University Amsterdam)  
“Spatial and spectral coherent control with frequency combs”

chair: Giel Berden

17.15 Poster Introduction – 1 minute per poster (P37 t/m P73)

18.00 Dinner (restaurant) (attach posters)

19.15 Poster presentations (Europa room, please remove posters after the evening lecture)

21.15 Evening lecture chair: Robert Spreeuw
Erik Verlinde (Institute for Theoretical Physics, University of Amsterdam)  
“Gravity as an emergent force”

POSTERS AND ORAL PRESENTATIONS
For oral contributions we have a limited time of 12 minutes per presentation (+3 minutes for discussion). The posters can be placed before or during the dinner.

Before 24.00 hr all posters must be removed. (The room will be cleaned)
**Wednesday 10 October 2012**

**08.00**  Breakfast (restaurant, please remove the luggage from your room)

*chair: Femius Koenderink*

**08.45**  
I3  **Vahid Sandoghdar** (Max Planck Institute for the Science of Light, Erlangen, Germany)  
“On the efficient interaction of single photons and single emitters”

**09.30**  Short talks (Europa room)

**O11**  **A. Mohtashami** (FOM Institute AMOLF)  
“Suitability of nanodiamond NV centers for spontaneous emission control experiments”

**O12**  **M. Yorulmaz** (MoNOS, LION, Leiden University)  
“Luminescence quantum yield of single gold nanorods”

**O13**  **Zili Zhou** (Eindhoven University of Technology)  
“Picosecond N-photon autocorrelator based on superconducting nanodetectors”

**O14**  **D. Akbulut** (University of Twente)  
“Optical transmission matrices of strongly scattering nanowire layers”

**10.30**  Coffee/tea break

*chair: Herman Offerhaus*

**11.00**  
I4  **Maria Loi** (University of Groningen)  
“The role of charge transfer excitons in bulk heterojunctions solar cells”

**11.45**  Short talks (Europa room)

**O15**  **Jeroen Cottaar** (Eindhoven University of Technology)  
“Scaling theory for percolative charge transport in disordered molecular semiconductors”

**O16**  **M.C. Fravventura** (Opto-electronic Materials Section, Delft University of Technology)  
“Determination of exciton diffusion length in thin evaporated organic films”
Wednesday 10 October 2012

O17 A.C.W. van Rhijn (Optical Sciences group, Mesa+ Institute for Nanotechnology, University of Twente)
“Experimental evolutionary optimization of phase shaped CARS”

O18 Jeroen Jalink (Spectroscopy of Solids and Interfaces, IMM Radboud University)
“Electron-phonon coupling in cobalt clusters”

12.45 Lunch

chair: Giel Berden

13.55 Presentation winner poster award

chair: Wim Vassen

14.00 Short talks (Europa room)

O19 M.P. Bakker (Leiden University)
“Real-time monitoring of the formation of micropillar cavity modes in a semiconductor”

O20 W. Pfaff (Kavli Institute of Nanoscience Delft)
“Entanglement by measurement of solid-state qubits”

14.40 Randolf Pohl (Max Planck Institute for Quantumoptics, Garching, Germany)
“Proton structure from muonic hydrogen spectroscopy
- The proton radius puzzle”

15.20 Finish
**Poster Program**

**P1** Denis D. Arslanov • Molecular and Laser Physics, IMM Radboud University Nijmegen
Optical parametric oscillator based photoacoustic detection of hydrogen cyanide for bio-medical applications.

**P2** A.C. Assafrao • Delft University of Technology. Netherlands
Direct measurement of the near-field super resolved focused spot in an InSb thin layer.

**P3** Muharrem Bayraktar • MESA+ Institute for Nanotechnology, University of Twente
Reflective pyramid wavefront sensor for EUV radiation.

**P4** Joost van den Berg • KVI Atomic Physics, University of Groningen
Deceleration and trapping of heavy diatomic molecules.

**P5** Felipe Bernal-Arango • FOM Institute AMOLF
Hybridized plasmonic antennas on dielectric waveguides.

**P6** J. Biesheuvel • Laserlab, VU University Amsterdam
High-precision spectroscopy of the molecular hydrogen ion HD+

**P7** P.C Bons • Nanophotonics, Debye Institute, Utrecht University
Spin drag in a Bose gas.

**P8** J.S. Borbely • Laserlab, VU University Amsterdam
Ultracold metastable helium atoms in an optical dipole trap.

**P9** Leon Boschman • KVI Atomic Physics, University of Groningen
Unveiling PAH-catalyzed H₂-formation in the Interstellar Medium.

**P10** R. Centeno • Molecular and Laser Physics, IMM Radboud University Nijmegen
Ultrasensitive Quantum Cascade Laser spectroscopy for heterodyne detection of exhaled biomarkers.

**P11** A. U. Chaubal • Zernike Institute for Advanced Materials, University of Groningen
Detecting spin-flip Raman light: challenges and technical advances towards quantum entanglement.

**P12** Ting Lee Chen • MESA+ Institute for Nanotechnology, University of Twente
The linear and nonlinear properties of Sierpinski fractal optical nano-antenna.

**P13** Philip Chimento • Huygens Laboratory, Leiden University
Anomalous surface Plasmon dispersion in aluminum.

**P14** T. Denis • MESA+ Institute for Nanotechnology, University of Twente
Relaxation oscillation of the wave front tilt in a photonic free-electron laser.

**P15** G. D. Dickenson • Laserlab, VU University Amsterdam
Precision measurements of the ground state of molecular hydrogen.

**P16** Dirk Jan Dikken • MESA+ Institute for Nanotechnology, University of Twente
Controlled excitation of higher-order subradiant plasmonic modes in nanostructures.

**P17** P.W.M. Elroy • Utrecht University
Spinor preparation in a Bose-Einstein condensate.

**P18** Martin Frimmer • FOM Institute AMOLF
Hybrid photonic systems – super-radiance at the unitary limit.

**P19** Erik T. Garbacik • MESA+ Institute for Nanotechnology, University of Twente
Applications of hyperspectral CARS microscopy.

**P20** Juehan Gao • FOM Rijnhuizen, Nieuwegein
Gas-phase infrared spectroscopy of anionic polyaromatic species.

**P21** S.J. Goh • MESA+ Institute for Nanotechnology, University of Twente
Characterization of high harmonic beams for seeding of free-electron lasers.

**P22** S.A. Goorden • MESA+ Institute for Nanotechnology, University of Twente
High-resolution phase and amplitude modulation using digital micromirror devices.
Poster Program

P23  Josipa Grzetic • FOM Rijnhuizen, Nieuwegein
Dissociation reactions of peptides with glutamine or asparagine residues.

P24  Z. Gu • Laserlab, VU University Amsterdam
Laboratory study of Rayleigh-Brillouin scattering in air for measuring the winds of the Earth.

P25  M.A. Haddad • Laserlab, VU University Amsterdam
Electronic spectra of D- and 13C-substituted linear carbon chains C_{2n}H (n=4 - 6).

P26  S. Jaeqx • FOM Rijnhuizen, Nieuwegein
Elucidating structural information of peptides by using the far-infrared spectroscopy.

P27  Jaime Gómez Rivas • FOM Institute AMOLF, COBRA Research Institute, Eindhoven
Plasmonic light emission.

P28  D.M. Kiawi • FOM Rijnhuizen, Nieuwegein
IR spectroscopy of Fe and FeS clusters.

P29  Steven Knoop • Laserlab, VU University Amsterdam
Trap loss of ultracold metastable helium: non-exponential one-body loss and magnetic-field-dependent wo- and three body loss.

P30  Servaas Kokkelmans • Department of Physics, Eindhoven University of Technology
Feshbach resonances in Cesium at ultra-low static magnetic fields.

P31  Andrej Kwadrin • FOM Institute AMOLF
Gray-tone lithography implementation of Drexhage’s method for calibrating radiative and nonradiative decay constants of fluorophores.

P32  Joan Hsiao Hui Lee • MESA+ Institute for Nanotechnology, University of Twente

P33  V.Y.F. Leung • Van der Waals-Zeeman Institute of Physics, University Amsterdam
Hopping of dipolar excitation on a lattice of Rydberg atoms.

P34  V.Y.F. Leung • Van der Waals-Zeeman Institute of Physics, University Amsterdam
Magnetic Lattice Atom Chips for Quantum Information Science.

P35  W. Lewoczko-Adamczyk • Van der Waals-Zeeman Institute of Physics, University Amsterdam
Manipulating a 1D Bose gas on an atom chip.

P36  W. Löffler • LION, Leiden University
Spatial photon entanglement and binary coding.

P37  F. Mariani • Huygens Laboratory, Leiden University
Optical scattering in quasi-2d geometries.

P38  Corine Meinema • KVI Atomic Physics, University of Groningen
Towards a parity violation measurement using ultracold molecules.

P39  M. Mesta • Eindhoven University of Technology
Computational modeling of charge injection, transport and exciton generation in OLEDs.

P40  L. Midolo • Eindhoven University of Technology
Electromechanical control of the spontaneous emission rate of quantum dots in photonic crystal cavities.

P41  J. Morgenweg • Laserlab, VU University, Amsterdam
New laser system for highly accurate direct frequency comb spectroscopy.

P42  Stefan Müller • KVI Atomic Physics, University of Groningen
Lorentz Invariance on Trial in the Weak Interaction.

P43  B.O. Mussmann • Debye Institute for NanoMaterials Science, Utrecht University
Optical Transmission through hole-arrays and single holes.

P44  Julian Naber • Institut für Physik, Johannes Gutenberg-Universität Mainz
Experimental setup for exciting 40Ca+ ions into Rydberg states.
**Poster Program**

**P45** Pedro Navarro - Huygens Laboratory, Leiden University  
Spectral diffusion of single Dibenzoterrylene molecules in 2,3-dimethylanthracene.

**P46** Adrian J. de Nijs - Laserlab, Vu University, Amsterdam  
Microwave transitions in metastable CO to probe a possible variation of the proton-to-electron-mass ratio.

**P47** M. L. Niu - Laserlab, Vu University, Amsterdam  
High-resolution spectroscopy on the A-X band of CO for probing possible μ-variation.

**P48** Daniel Noom - Laserlab, Vu University, Amsterdam  
Coherent broadband soft-X-ray microscopy.

**P49** R.M. Oldenbeuving - MESA+ Institute for Nanotechnology, University of Twente  
SEGA mode locking, first experimental indications of operation.

**P50** A.R. Onur - Zernike Institute for Advanced Materials, University of Groningen  
Quantum optics with semiconductor spin ensembles.

**P51** K. Orsel - MESA+ Institute for Nanotechnology, University of Twente  
In-situ mapping of 3D material flux in PLD plasmas.

**P52** P.L.E.M. Pasmans - Eindhoven University of Technology  
Studying structural dynamics using ultrafast electron diffraction.

**P53** T.J. Pinkert - Laserlab, Vu University, Amsterdam  
Narrow bandwidth optical frequency references for high-accuracy extreme ultraviolet spectroscopy.

**P54** T.J. Pinkert - Laserlab, Vu University, Amsterdam  
Frequency comb generation by CW laser injection of a hybridly mode-locked quantum-dot laser.

**P55** J.C.J. Koelemeij - Laserlab, Vu University, Amsterdam  
SuperGPS through optical networks.

**P56** Marina Quintero-Pérez - Laserlab, Vu University, Amsterdam  
Decelerating and trapping ammonia molecules in a ring decelerator.

**P57** A.L. La Rooij - Van der Waals-Zeeman Institute of Physics, University Amsterdam  
Lattices of atom microtraps on magnetic-film atom chips.

**P58** Devasena Samudrala - Molecular and Laser Physics, IMM Radboud University Nijmegen  
Identification and detection of methyl salicylate using proton transfer reaction ion trap mass spectrometry.

**P59** Bodhaditya Santra - KVI Atomic Physics, University of Groningen  
Electric dipole moments in heavy atomic systems.

**P60** Divya Sharma - MESA+ Institute for Nanotechnology, University of Twente  
Ultrafast fluorescence quenching of porphyrin in graphene-porphyrin hybrid material.

**P61** A. Singh - MESA+ Institute for Nanotechnology, University of Twente  
Polarization-resolved phase-sensitive near-field microscopy on photonic-crystal waveguides.

**P62** G.B. Spenkelink - MESA+ Institute for Nanotechnology, University of Twente  
Selectively exciting Fabry-Perot cavity modes with a spatial light modulator.

**P63** Frans. R. Spiering - Molecular and BioPhysics, IMM Radboud University Nijmegen  
Absorption by molecular oxygen around 922 nm.

**P64** T.H. Taminiau - Kavli Institute of Nanoscience, Delft University of Technology  
Controlling individual nuclear spins in diamond with a single electron spin.

**P65** Y. Tao - MESA+ Institute for Nanotechnology, University of Twente  
Characterization of a cluster jet for quasi-phase matching of high harmonic generation.
**Poster Program**

**P66**  
**Atreju Tauschinsky**  
Van der Waals-Zeeman Institute of Physics, University Amsterdam  
Doppler-free electromagnetically induced transparency with Rydberg Atoms in Electric Fields.

**P67**  
**E. Verhagen**  
EPFL, Switzerland  
Quantum-coherent coupling of light to micromechanical motion.

**P68**  
**Paul Jansen**  
Laserlab, Vu University, Amsterdam  
Hindered internal rotation as a probe for drifting constants.

**P69**  
**Stefan Witte**  
Laserlab, Vu University, Amsterdam  
Lensless imaging using ultra-broadband light sources.

**P70**  
**S.H.W. Wouters**  
Eindhoven University of Technology  
Laser-cooled atomic beam ion source.

**P71**  
**M. Wubs**  
Technical University of Denmark  
Nanoplasmonics beyond the refractive index.

**P72**  
**Olger V. Zwier**  
Zernike Institute for Advanced Materials, University of Groningen  
New materials for quantum optics with spins and defects in semiconductors.
Electron imaging techniques are nowadays capable of precisely quantifying the position, type, and number of all atoms in nanostructures. With exposure times of minimally milliseconds, however, they are restricted almost exclusively to the study of equilibrium structures. Resolution of atomic motion both in space and time, i.e. 1 Å and 100 fs, would enable dynamical studies of, e.g., chemical reactions, phase transitions, and conformational changes at the most fundamental level. To realize this requires the development of entirely new ways of generating and handling pulsed electron beams.

Dense, ultrashort electron bunches cannot be extracted from traditional high-coherence, point-like emitters in electron microscopes. Usually they are generated by pulsed photoemission from flat metal cathodes which however lack coherence. We have developed a new, ultracold pulsed electron source, based on near-threshold photo-ionization of a laser-cooled gas, which is characterized by effective electron temperatures three orders of magnitude lower than conventional field or photoemission sources. The vastly improved coherence properties should make it possible to record high-quality diffraction patterns of macromolecular crystals in a single femtosecond exposure, which is nowadays only possible with the recently developed X-ray Free Electron Laser. The properties of the new source have been investigated in detail and first diffraction experiments are underway. Single-shot exposure requires packing millions of electrons in a tiny volume, tens of microns across, which inevitably leads to a rapid Coulomb expansion of the pulse and therefore loss of temporal resolution. We have developed a temporal electron lens, based on resonant radio-frequency (RF) techniques, to invert the Coulomb expansion. Using this technique, 0.2 pC, 100 keV electron bunches generated by regular photoemission, have been compressed from tens of ps down to sub-100 fs bunch lengths. In this setup pump-probe electron diffraction experiments are being carried out now on basic solid state samples. We are looking into other ways for phase space manipulation with RF cavities as well, such as dynamic aberration correction, which are not possible in conventional electron microscopes.
R.M.W. van Bijnen, D.J. Bakker,  
S.J.J.M.F. Kokkelmans, E.J.D. Vredenbregt  
*Eindhoven University of Technology*

**Ultrasound atomic gases are used extensively to realize textbook examples of condensed matter phenomena. Typically, such experiments deal with neutral atoms interacting via short-range VdW potentials much weaker than the Coulomb interactions between electrons in solids.**

In contrast, we study highly excited Rydberg atoms arranged on a lattice, representing a more accurate dilute model system for e.g. metallic conductors. Here, the interaction strengths approach Coulombic potentials, while retaining the controllability characteristic of cold atom experiments.  

In theory, such Rydberg lattices can be made to self-assemble out of a disordered gas using a tailored excitation scheme. Shaping the excitation laser beam into the desired structure beforehand greatly reduces experimental difficulties, although a tailored excitation scheme is still required to overcome the so-called Rydberg blockade. As a first step towards the creation of Rydberg lattices, we use a spatial light modulator to create arbitrary patterns of light. This light is used to ionize a cloud of cold atoms, creating arbitrarily shaped bunches of ions which are accelerated and imaged onto a detector.

A. Groot, P.C. Bons and P. van der Straten  
*Nanophotonics, Debye Institute for Nanomaterials, Princetonplein 1, Universiteit Utrecht*

**First and second sound are the hallmarks of two-fluid hydrodynamics. These sound modes consist of density and temperature modulations in the non-condensed and condensed fractions of an ultra-cold bosonic gas. By periodically modulating the trap potential a Faraday wave, or standing sound wave, is induced in the condensate. First, we have investigated the dispersion relation of this excitation, which can be used to extract the speed of sound with a very high accuracy.**

Secondly, our measurements give insight into the emergence and time evolution of these highly excited collective modes. Our analysis suggests the non-linear interactions and hydrodynamicity of the condensate allow for coupling between the radial driving and the emerging Faraday waves in the axial direction.
Single ion Ra⁺ Spectroscopy for atomic parity violation

KVI Groningen

The sensitivity of the APV signal grows faster than the third power of the atomic number Z. A single trapped Ra ion opens a promising path for a most precise measurement of atomic parity violation (APV). This will yield a precise measurement of the electroweak mixing angle in the Standard Model of particle physics. One requirement for this measurement is the localization of the ion within a fraction of an optical wavelength. For this, the current experiments are focused on trapping and laser cooling of few Ba⁺ ions as a precursor for Ra⁺. Ba⁺ ions are trapped and laser cooled in a precision hyperbolic Paul trap. Work towards single ion trapping of Ra⁺ is in progress. Online laser spectroscopy of trapped short-lived 209-214Ra⁺ isotopes in a linear Paul trap has been performed, at the same time hyperfine structure of the 6d² D3/2 states and isotope shift of the 6d² D3/2-7p²P1/2 transition have been measured. These results are required for the interpretation of an APV measurement in Ra⁺ and to required atomic theory.

Search for a cosmologically varying proton-to-electron mass ratio from methanol

Julija Bagdonaite¹, Paul Jansen¹, Christian Henkel², Rick Bethlem¹, Karl Menten², Wim Ubachs¹
¹ VU University Amsterdam
² Max-Planck-Institut für Radioastronomie, Germany

The Standard Model of physics is built on the fundamental constants of nature, however without providing an explanation for their values, nor requiring their constancy over space and time. The question of the assumed constancy over cosmological timescales can be addressed via quasar spectroscopy. The wavelengths of certain atomic or molecular spectral lines have well defined dependencies on the values of these constants. Thus, to experimentally search for the variation a comparison is made between highly accurate laboratory spectra and quasar spectra. Recently, rotational transitions of methanol have been identified as an extremely sensitive probe for the possible variation of the proton-to-electron mass ratio. Based on measurements with the Effelsberg 100-m radio telescope, a study of methanol absorption lines is presented towards the gravitationally lensed system PKS1830-211 at a look-back time of 7 billion years.
Massive mechanical objects are now becoming available as new systems for quantum science. Quantum optics provides a powerful toolbox to generate, manipulate and detect quantum states of motion of such mechanical systems - from nanomechanical waveguides of some picogram to macroscopic, kilogram-weight mirrors of gravitational wave detectors. Recent experiments, including laser-cooling of massive mechanical devices into their quantum ground state of motion [1], and demonstrations of the strong coupling regime [2] provide the primary building blocks for full quantum optical control of mechanics, i.e. quantum optomechanics [3].

This has fascinating perspectives for both applications and for quantum foundations: For example, the on-chip integrability of nano- and micromechanics, together with their flexibility to couple to different physical systems, offers a novel perspective for solid-state quantum information processing architectures. At the same time, the mass of available mechanical resonators provides access to a hitherto untested parameter regime of macroscopic quantum physics via the generation of superposition states of massive systems and of optomechanical quantum entanglement, which is at the heart of Schroedinger’s cat paradox [4]. Finally, due to the large mechanical mass, table-top quantum optomechanics experiments should even allow to explore the interface between quantum physics and (quantum) gravity [5].

Spatially entangled 4-photon states from periodically poled potassium-titanyl-phosphate crystal

S. Cigdem Yorulmaz, Alexander J.H. van der Torren, Jelmer J. Renema, Martin P. van Exter, and Michiel J.A. de Dood

Spontaneous parametric down conversion is a convenient process to generate multi-photon states that are fundamental resource for quantum metrology and quantum imaging. We create spatially entangled 4-photon states at 826.4 nm wavelength by pumping a 2 mm long periodically poled KTP crystal with a 2 ps laser pulses. The intense pump enables a non-negligible rate of 4-photon events, which are either 2 independent pairs, created by spontaneous emission, or a genuine 4-photon state as a result of stimulated emission of a photon pair. We demonstrate experimentally that spatially entangled 4-photon states can be distinguished from double pairs. The spatial domain offers the distinct advantage over other approaches that high spatial resolution can be easily achieved by selecting appropriate lenses and apertures. We reach visibilities of 25% of the 4-photon state for a pump beam waist of 80 µm in the experiment. The visibility depends strongly on the number of available spatial and temporal modes, which can be controlled by the focus of the pump beam, size of the detector aperture and filtering in the frequency domain.

Quantum optics with semiconductor spin ensembles

A.R. Onur¹, A.U. Chaubal¹, J. Sloot¹, J.P. de Jong¹, O.V. Zwier¹, R.S. Lous¹ D. Reuter², A.D.Wieck², C.H.van der Wal¹

1 Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands
2 Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

We present quantum optical studies with ensembles of donor-bound electron spins in ultra-pure GaAs materials with Si doping at very low concentrations (10¹³⁻¹⁰¹⁴ cm⁻³). These donor-bound electrons (D⁰ systems) provide unique system properties for solid state quantum information processing, since they combine a high level of ensemble homogeneity (as for atomic vapors) with strong optical transitions and the ability to nano-fabricate and integrate very compact optoelectronic devices with semiconductor processing tools. Specifically, we report the observation of dynamic nuclear polarization in this material [1], using electromagnetically induced transparency as a driving mechanism and as a probe for the effective magnetic (nuclear Overhauser) field.

Polycyclic aromatic hydrocarbons (PAHs) are an important and ubiquitous component of the interstellar medium. In order to link energy deposition to specific fragmentation channels, we performed the CIDEC method which allows us to determine the excitation energy of a molecular dication, in coincidence with time-of-flight data of the cationic fragmentation products. Very surprisingly, we observed a strong dominance of emission of C$_3$H$_3^+$ over the anticipated C$_2$H$_2^+$ loss channel (figure). In order to explain this unexpected behaviour, we performed DFT calculations, which showed that C$_3$H$_3^+$ emission is favourable over C$_3$H$_3$ emission, while C$_2$H$_2^+$ and C$_2$H$_2$ show the opposite behaviour. Thus, we found experimental evidence for alternative pathways in PAH fragmentation, which could be fully explained by DFT calculations.

The “grand” polycyclic aromatic hydrocarbons (PAHs) in space are highly stable. Laboratory studies have however been restricted to small PAH sizes. We present infrared multi-photon dissociation (IRMPD) employing a mass spectrometer located inside the cavity of the FELICE (Free Electron Laser for Intra-Cavity Experiments). The high photon intensity allows for IRMPD of very stable (difficult to dissociate) species. We recorded the IR spectrum of the phenyl cation (5.5–30 µm) and confirm the singlet state configuration of its electronic ground state. We investigated the formation of the almost iso-energetic singlet and triplet state of the napthyl cation depending on production method. We present similar IR spectra for C$_{13}$H$_9^+$ generated from fluorine, dihydroanthracene, and dihydrophenanthrene, suggesting the concurrent formation of the fluorenyl ion, giving insights on pathways of CH$_2$ loss for dihydroanthracene and dihydrophenanthrene. These FELICE experiments hold great promise to obtain IR spectra of grand PAHs.
Development of the external cavity quantum cascade laser for spectroscopic applications

D. Marchenko, J. Mandon, S.M. Cristescu, F.J.M. Harren
Radboud University Nijmegen

Distributed Feed Back Quantum Cascade Lasers (DFB QCLs) are widely used nowadays for all kind of spectroscopic applications. However, the drawback of DFB QCLs is that they are typically designed for operation at a single target frequency at which they can be tuned over a narrow range (0.1-2 cm⁻¹). This tuning range is only sufficient to resolve a targeted ro-vibrational absorption line of a molecule. Therefore, for each specific wavelength (and every specific molecule) another QC laser has to be designed and manufactured. In the present work, we focus on the development of a widely continuous tunable, mode hop free External Cavity Quantum Cascade Laser (EC-QCL). We implemented several key issues to improve the EC architecture in order to achieve wide tuning range (> 200 cm⁻¹ within the 6-9 µm spectral region), fast tuning speed (>1 kHz full scanning range) and high resolution (< 0.001 cm⁻¹). This will offer us a wide coverage in the mid-infrared region for further spectroscopic applications in the medical research field.

Spatial and spectral coherent control with frequency combs

I. Barmes, S. Witte, and K.S.E. Eikema
LaserLaB Amsterdam, VU University, Amsterdam, the Netherlands

We demonstrate high resolution spatial and spectral control over atomic excitation by manipulating quantum interference in a simple two-level system. In broadband excitation of a two-photon transition many pairs of frequencies participate simultaneously in the excitation process and the relative phases between the pairs determine the final transition amplitude. We show that by using counter-propagating pulse trains, control can be achieved not only in frequency but also in space. By appropriately shaping the pulses we acquire complex spatial excitation patterns as well as complete elimination of single-sided Doppler-broadened signal. The combination of spectral and spatial control enabled us to perform high-precision frequency comb spectroscopy on rubidium atoms at 2x760 nm as well as spatial separation of different species in a multi-component environment.
Evening lecture
Gravity as an emergent force

Erik Verlinde
Institute for Theoretical Physics,
University of Amsterdam

Current developments in string theory and black hole physics indicate that gravity should be viewed as an emergent phenomenon that is derived from an underlying microscopic description. The analogy between gravity and thermodynamics suggests that entropy plays an important role in the emergence of gravity, while other important clues come from certain dualities found in string theory. Following these insights I will explain the basic mechanisms responsible for the emergence of gravity. It appears that the observed phenomena associated with dark matter may be naturally explained in this scenario.
On the efficient interaction of single photons and single emitters

V. Sandoghdar

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In the 1990s, many pioneering experiments demonstrated the potential of single organic molecules embedded in solids as quantum mechanical two-level systems. However, coherent interactions were not studied because those experiments relied on recording the fluorescence signal, which only accesses populations of the excited state and not the coherences. Recently, we showed theoretically that in the linear excitation regime, an atom can block a propagating light beam by up to 100% if it is confined to an area comparable with its scattering cross section [1].

I will present an overview of our recent experimental work on the efficient interaction of light and single organic molecules both in the near and far fields [2, 3]. We will see that at T<2K, a single molecule can attenuate [2, 3], transmit, amplify [4] or phase-shift [5] a focused laser beam. Furthermore, I will report on the first direct long-distance communication of two optical emitters via single photons [6]. I will then discuss strategies for the optimization of the interaction between single photons and single emitters via, e.g. ultra-high collection efficiency [7, 8] or enhancement of spontaneous emission [9] by using plasmonic and dielectric antennas.

Suitability of nanodiamond NV centers for spontaneous emission control experiments

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Reliable single photon sources are key for quantum optical communication and computation. The nitrogen-vacancy (NV) color center in diamond has been identified as a promising candidate with remarkable photostability at room temperature. In our group we seek to enhance single photon sources for instance by placing nanodiamond particles with NV centers inside plasmonic structures. Here, we ask how one selects the most suitable nanodiamond from an ensemble, prior to laborious nanofabrication. In addition to quantifying the surprisingly broad brightness and decay rate distributions of nanodiamonds, we report on a method to calibrate quantum efficiencies of single NV centers. Using reversible, controlled and calibrated LDOS variations applied by a micromechanical mirror, we show that contrary to common opinion, the quantum efficiency of nanodiamond NV centers is widely distributed between 0 and 100%.

Luminescence quantum yield of single gold nanorods

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Gold nanoparticles are of great interest as probes because of their optical properties provided by the collective oscillation of their conduction electrons, surface plasmon. They can be prepared in small sizes and different shapes changing their optical properties and bringing them to the region of interest.

We study the luminescence quantum yield (QY) of single gold nanorods with different aspect ratios and volumes [1]. Compared to gold nanospheres [2], we observe an increase of QY by about an order of magnitude for particles with a plasmon resonance >650 nm. Moreover, we identify two components which contribute to the luminescence spectrum, one around 500 nm and one coinciding with the longitudinal plasmon band, by correlating scattering and luminescence spectra and performing polarization sensitive measurements. Our study contributes to the understanding of luminescence from gold nanorods for their applications in biological and soft matter studies.

[1] Mustafa Yorulmaz; Saumyakanti Khatua; Peter Zijlstra; Alexander Gaiduk; Michel Orrit, Nano Letters, submitted
We present a novel $N$-photon autocorrelator with high sensitivity and picosecond temporal resolution. It is realized by combining an interferometer with a superconducting nanodetector as shown in Fig.1 (inset), which provides single/multiphoton response depending on the bias current ($I_b$). By setting the autocorrelator in $N$-photon regime ($N=1,2,3,4,5,6$), up to 6th-order photon autocorrelations have been measured at ultralow power levels in the range of pW~nW. The autocorrelator’s temporal resolution is limited by intrinsic response time $\tau_{in}$ of the nanodetector which has been determined by illuminating the nanodetector with two short pulses with a variable delay. As shown in Fig.1, by fitting the measured photocounts as a function of the delay, $\tau_{in}$ was determined to be ~20 ps.
Optical transmission matrices of strongly scattering nanowire layers

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Light transport through a scattering material takes place via open transport channels with transmission coefficient close to 1 [1, 2]. If the material is strongly scattering, only a small portion of all transport channels is open. Having small number of open transport channels gives rise to correlations in the optical transmission matrix, which have not been observed so far.

We measure optical transmission matrices of strongly scattering GaP nanowire layers [3], one of the strongest scattering samples in the visible region. We investigate correlations in the measured transmission matrices.


Scaling theory for percolative charge transport in disordered molecular semiconductors

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Charge transport in organic semiconductors is described by hopping of carriers between localized sites. Theoretically determining the charge mobility in these materials requires expensive 3D simulations. Semi-analytical approximations based on percolation theory are available, but do not accurately match the simulation results (see figure).

We present a scaling theory for this charge transport that extends percolation theory by considering more than one critical bond. This leads to a compact expression for the mobility for Miller-Abrahams or Marcus hopping on different lattices with uncorrelated or dipole-correlated Gaussian energy disorder. An important conclusion is that the charge-density dependence is universal.

The role of charge transfer excitons in bulk heterojunctions solar cells

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Photovoltaic devices based on organic bulk heterojunctions have recently gained renewed interest because of the achievement of power conversion efficiencies above 10%. These latest results showed that this class of devices are not only an interesting research topic but can have also economical relevance. Nevertheless, it is also clear that not all the physical questions on their working mechanism are answered and that the use of new polymers, in particular the one with narrow band-gap, pose new interesting questions.

In this presentation I will show that the narrow band-gap polymer bulk heterojunctions offer a new opportunity to shed light on the charge separation phenomena and on the photo-excitation involved in the working mechanism of organic solar cells. I will report different examples were charge transfer excitons play a main role in the photoexcitation landscape and I will discuss their importance for the performance of bulk heterojunction solar cells.

Determination of exciton diffusion length in thin evaporated organic films

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A heterojunction based on a phthalocyanine (Pc) as electron donor and C₆₀ as electron acceptor is attractive as photoactive layer in organic photovoltaics. The transport of excitons, i.e. bound electron/ hole pairs, is an important factor determining the efficiency of such devices. In this work we investigate the exciton diffusion length ($\Lambda_E$) with the electrodeless time-resolved microwave conductance (TRMC) technique. To determine $\Lambda_E$ in C₆₀, bilayers of 30 nm Zn-Pc with a C₆₀ layer with variable thickness are prepared by physical vapour deposition. Analysis of the photoconductance with an exciton diffusion model yields $\Lambda_E = 7$ nm in the C₆₀ film. From analysis of the rise and decay of the TRMC transients we attribute the photoconductance to diffusion and dissociation of singlet excitons rather than triplets. The energy transfer rate between C₆₀ molecules exceeds $8 \times 10^{10}$ s⁻¹ and it cannot be described by the Förster model due to the close proximity of the fullerenes. In Pc films, the orientation of the macrocycles, which can be manipulated by the deposition parameters, strongly affects the optoelectronic properties. The relationship between $\Lambda_E$ in these layers and the arrangement of the Pc molecules is discussed.

Experimental evolutionary optimization of phase shaped CARS

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Coherent anti-Stokes Raman scattering (CARS) spectroscopy and microscopy rely on vibrational resonances to distinguish molecules. In conventional narrowband CARS, the chemical contrast is based on a single vibration. In more complex samples, such as mixtures or samples containing many different compounds, contrast based on a single resonance may not be sufficient. We present a broadband CARS approach, using a degenerate broadband pump and probe pulse in combination with a narrowband Stokes pulse, where multiple resonances are excited simultaneously. Contrast is obtained by phase shaping the broadband pump and probe pulse, influencing the interference between the different pathways in this broadband CARS process. Using an evolutionary algorithm we are able to optimize for different molecules and obtain background-free images with high chemical selectivity.
Electron-phonon coupling in cobalt clusters

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We present a method to probe the electronic density of states in nano-sized neutral transition metal clusters. Initially cold (77 K) cobalt clusters are heated by resonant excitation of vibrational coordinates. The absorbed energy is statistically redistributed over the nuclear and electronic degrees of freedom through the electron-phonon coupling. We probe the modification of the electronic population near the Fermi level by UV spectroscopy. The electronic temperature is derived using a Fermi-Dirac statistical population of the available electronic states and temperatures exceeding several hundred Kelvin are inferred. The experiment demonstrates that the electron-phonon coupling can be studied in finite-sized systems where the energy is selectively deposited in phonon modes only. The double-resonance nature of the detection scheme opens the possibility to carry out time-resolved studies of the electron-phonon coupling dynamics.

Real-time monitoring of the formation of micropillar cavity modes in a semiconductor

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Embedded self-assembled InAs quantum dots (so-called artificial atoms) inside a semiconductor microcavity form an interesting system to study cavity quantum electrodynamics in the solid-state. Cavities are formed by an active region containing QDs sandwiched by two GaAs/Al₀.₉Ga₀.₁As distributed Bragg reflector mirrors. The optical mode confinement is maximized by an additional oxide aperture layer. The oxidation takes place by etching micropillars and through wet oxidation. The challenge now is to monitor this process. In this contribution I will discuss a technique to probe the buried oxide layers by looking at the difference in reflectivity layers of the side lobes of the DBR stopband. By taking quick spatial scans we can monitor the oxide growth, and thereby the formation of the cavity modes, close to real-time.
Entanglement by measurement of solid-state qubits

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**Projective** measurements are a powerful tool for manipulating quantum states. In particular, measurements can entangle qubits that do not interact directly. This makes entanglement by measurement a promising approach for well-isolated solid-state qubits that are hard to entangle by coherent interactions. However, the demanding experimental requirements have so far hindered realizations.

Here we demonstrate the generation of highly entangled states between two nuclear spin qubits in diamond by a projective quantum measurement. Using non-destructive readout of an ancillary NV center electron by resonant optical excitation we are able to project the nuclear spins into Bell states, demonstrating for the first time entanglement between two solid-state nuclear spins. Combining with single-shot readout of the nuclear spins we achieve the first violation of Bell’s inequality with solid-state spins.

The demonstrated projective measurements form the basis for measurement-based two-qubit gates and quantum error correction. Our results introduce a new class of experiments that use projective measurements to create, protect and manipulate entangled states of solid-state qubits.

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Proton structure from muonic hydrogen spectroscopy
- The proton radius puzzle

Randolf Pohl
for the CREMA collaboration*

Muonic hydrogen ($\mu p$) is the exotic hydrogen atom where a proton is orbited by a negative muon, the “heavy cousin” of the electron. The $\sim$200 times larger muon mass leads to an about 200 times smaller Bohr radius in $\mu p$, compared to regular hydrogen (H). The resulting $\sim 200^3 \approx 10^7$ times larger wave function overlap of the muon and the proton leads to a $10^7$ times enhancement of the finite size effect of S states in $\mu p$, compared to H. In fact, the $r_p$ dependent contributions amount to as much as 2% of the 2S Lamb shift. Consequently, laser spectroscopy of the Lamb shift (2S-2P energy splitting) in muonic hydrogen ($\mu p$) [1] has long been considered the most sensitive method to determine the root-mean-square charge radius $r_p$ of the proton [2]. We have recently determined $r_p = 0.84184(67)$ fm [1], ten times more accurate than any previous determination [2] from either H spectroscopy or elastic electron-proton-scattering, but 7 sigma away. This so-called “proton radius puzzle” has attracted a lot of interest from atomic and nuclear physics as well as physics “beyond the Standard Model”. Laser spectroscopy of muonic hydrogen, deuterium and helium isotopes may shed new light on the radius puzzle. Our measurement of a second 2S-2P transition in muonic hydrogen [3] has enabled us to determine the 2S hyperfine splitting in $\mu p$. From this we extract the Zemach-radius $R_Z$ of the proton which parametrizes the magnetization distribution inside the proton. Our value of $R_Z$ is in good agreement with previous determinations, but a bit less precise. On the other hand, this new data confirms our previous value of $r_p$, strengthening the severity of the charge radius puzzle. Data from muonic deuterium is presently being analyzed, and our new project “CREMA” (Charge Radius Experiment with Muonic Atoms) aims at the measurement of several 2S-2P transitions in hydrogen-like muonic $^3$He and $^4$He ions [4].


*The CREMA collaboration:
Optical parametric oscillator based photoacoustic detection of hydrogen cyanide for bio-medical applications

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A versatile continuous wave optical parametric oscillator-based photoacoustic spectrometer was developed for long-term trace gas emission experiments on volatile compounds emitted by biological samples. The OPO-based spectrometer had (wavelength coverage 2.8 - 3.8 µm, linewidth 8 MHz and an output power of 1 W) was successfully tested for the detection of HCN (hydrogen cyanide) emission from clover leaves, apple seeds and Pseudomonas bacteria next to its presence in exhaled human breath. For specific experiments the spectrometer operated continuously up to 10 days and showed a detection limit of 0.4 ppbv of HCN in 10 s, using the P₈ rotational line in the ν₃ vibrational band at 3287.25 cm⁻¹.

Direct measurement of the near-field super resolved focused spot in an InSb thin layer

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The Super resolution near field effect (Super-RENS) is a promising technique to break the fundamental diffraction limit in optical systems. In this technique, a focused laser beam incident upon a thin layer of an InSb-based semiconductor generates a reversible subwavelength optical scatterer, which interacts with the incident focused spot, resulting in a localized focused spot not limited by diffraction.

We combined near field microscopy, confocal microscopy and time resolved pump probe technique to directly measure a thermally induced sub-diffraction limited spot, in the near-field regime. The measured spot size was found to be dependent on the laser power and a decrease of 25% (100nm) was observed. Excellent agreement with a rigorous simulation model was also found.
**P3 Reflective pyramid wavefront sensor for EUV radiation**

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There is a need to monitor the wavefront of EUV radiation from different sources like free electron lasers, synchrotrons or plasma generated sources that are used in next generation lithography machines in the semiconductor industry. Here, we present a new type of pyramid wavefront sensor, which operates in the reflective rather than in the transmittive mode due to the lack of transmittive optical materials at EUV wavelengths.

The incoming beam of which the wavefront has to be measured is focused on the tip of a small pyramid coated with a EUV multilayer coating. The four facets of the pyramid reflect the four parts of the beam towards a second mirror which image the beams on an EUV CCD camera. The two Fourier transforms caused by the two mirrors and the four wavefront tilts yield enough information to reconstruct the wavefront. Results of a full simulation of our design will be presented.

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**P4 Deceleration and trapping of heavy diatomic molecules**

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We are constructing an experiment that extends the range of molecules that can be decelerated and trapped to heavier and more complex species. Our experimental approach is based on a Stark ring-decelerator. Inside the tube created by the ring-shaped electrodes, a series of moving traps is created with a computer-controllable velocity. We will first apply this technique to the deceleration of the SrF molecule, which is a promising candidate for a measurement of parity violation.

On this poster we will present the concept, design and status of the molecular beam source and the decelerator.
Hybridized plasmonic antennas on dielectric waveguides

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AMOLF

Controlling emission and absorption of photons by nanoscale sources is of key importance for ultrasmall sources, detectors, quantum computing and microscopy. In order to achieve such control we propose an approach in which a gold nano-antenna coupled to a dielectric waveguide cooperate to get close to 100% coupling and detection efficiencies of the photons produced by single emitters. To understand this system we have studied the scattering properties of single gold nano-rod and Yagi-Uda antennas placed over SiN waveguides. The scattering processes observed are well understood as the effects of dipolar objects placed in a planar layered environment. We report measurements of the spectrum as well as directionality of the guided mode scattering by the antennas. Also we have measured in-coupling due to the antennas of free space incident light into the waveguide modes. We find a strong directional dependence in this scattering process for the Yagi-Uda antennas.

High-precision spectroscopy of the molecular hydrogen ion HD⁺

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The uncertainty of theoretical energy level calculations of the molecular HD⁺ ion is substantially limited by the uncertainty in fundamental constants. Therefore, comparison with highly accurate experimental data can produce improved values of fundamental constants. We have set up an apparatus for high-precision spectroscopy of trapped, laser-cooled HD⁺ ions. Using resonance-enhanced multiphoton dissociation (REMPD) we have obtained high-resolution optical spectra of the (v, J): (0,2) → (8,3) overtone at 782 nm, which may be used for a new determination of the proton-electron mass ratio. Furthermore we have observed spin-flip transitions using oscillating magnetic fields combined with REMPD detection. This can be used to measure hyperfine splittings, from which the proton size can be derived. To interpret the results we use a model which takes into account the REMPD process, the redistribution of the rotational-state population by blackbody radiation, and hyperfine structure of rovibrational levels.
Spin currents are subject to strong damping due to collisions between spin components, a phenomenon known as spin drag. We have performed spin drag experiments for ultra-cold sodium atoms in the condensed and non-condensed phase. We prepare a mixture of the hyperfine levels of the F=1 sodium ground state and set the components into relative motion. In the non-condensed phase, a constant drift velocity between the spin components develops, which is a measure of spin drag. Close to the phase transition to BEC we observe a strong increase of spin drag due to Bose enhancement acting as a precursor for Bose-Einstein condensation. In the condensed phase the components become immiscible. We have performed experiments where we direct the components at each other but they do not penetrate through each other. The force associated with the immiscibility is too small to cause such a strong repulsion. We expect that the hydrodynamicity of the system plays a large role.

Unveiling PAH-catalyzed H₂-formation in the Interstellar Medium

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Polycyclic aromatic hydrocarbons (PAHs) have been detected in the interstellar medium and it is believed that they catalyze the formation of molecular hydrogen out of atomic hydrogen. In this catalytic process, hydrogen atoms attach to PAHs. Hydrogen abstraction can only be induced upon attachment of another hydrogen atom from the gas phase and subsequent formation of a hydrogen molecule in the process. The rate of attachment to the PAH is determined by the height of the barrier the H atom has to overcome. This barrier height has not been experimentally accessible, yet.

We have exposed an ensemble of trapped coronene cations (C₂₄H₁₂⁺) to a beam of atomic hydrogen and subsequently performed mass spectrometry of the reaction products. Exclusively addition of an odd number of hydrogen atoms was observed, indicating that every second hydrogen addition has a barrier. Using different hydrogen temperatures and irradiation times we are able to determine the height of this barrier, which is paramount to the rate of H₂ formation.

Ultrasensitive Quantum Cascade Laser spectroscopy for heterodyne detection of exhaled biomarkers

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External Cavity Quantum Cascade Lasers (EC-QCLs) are attractive sources for development of non-invasive, compact gas sensors. To achieve real-time analysis of trace gases in human breath, we propose to combine External Cavity Quantum Cascade Lasers (EC-QCLs) with Noise-Immune Cavity Enhanced Optical Heterodyne Molecular Spectroscopy (NICE-OHMS), an ultra-sensitive detection method mainly used for sub-Doppler resolution molecular spectroscopy. The wide tunability combined with the high sensitivity and resolution of the spectrometer promises extensive applications.

As a first step, we applied a Pound-Drever-Hall (PDH)-frequency stabilization scheme to achieve high precision stabilization. By direct modulation of the laser current at 20 MHz, the laser frequency is locked to the Fabry–Perot cavity containing the analyzed gas. The first results are focusing on the fluctuations in the resonator happening on different time scales reaching from minutes down to microseconds. On-going work is now concerning the implementation of the NICE-OHMS detection scheme, which was hardly anywhere applied to EC-QCLs.
Detecting spin-flip Raman light: challenges and technical advances towards quantum entanglement

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We develop detection of spin-flip Raman light from localized donor-bound electron ensembles (D⁰ systems) in n-GaAs as a path to realizing quantum entanglement. The donor electrons behave as alkali atoms with one 1-s electron. In a magnetic field these systems form an optical lambda scheme (Fig. 1a). Our approach gives high optical densities with strong light-matter interactions. Our demonstration of electromagnetically induced transparency (Fig. 1b) confirms the versatility of this system for studies of quantum photon statistics, slowing light and measurement-based entanglement with solid state devices. Distinguishing the 40 GHz separated transitions is partly realized inside a fiber-based cryogenic microscope by polarization filtering.

The linear and nonlinear properties of Sierpinski fractal optical nano-antenna

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Fractal geometry has already been used in designing the broadband antennas for wireless communications, the “self-similarity” of fractal shapes is necessary for the frequency-independent RF antenna. However, the applications of fractal geometry in optical frequency range (~hundreds of THz), i.e. fractal optical nano-antennas, are still lacking explorations. In Optical Science group we numerically and experimentally explored the scattering spectrum and two photon-photoluminescence (TPPL) hot spots distributions of Sierpinski carpet optical nano-antennas made by gold. Comparing with random and periodic nano-structures, we found, by scattering spectrum measurements and FDTD numerical simulations, Sierpinski carpet optical nano-antenna has strong interference effect between local surface plasmon (LSP) mode and evanescent wave mode (Fano resonance).
Anomalous surface plasmon dispersion in aluminum

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In plasmonics, we prefer metals with low losses. Aluminum, like gold and silver, has low loss, except for the wavelength region around 830 nm where its reflectivity takes a small nosedive. However, this higher-loss region is interesting because it implies the possibility of anomalous dispersion for surface plasmons.

Based on the bulk permittivity of aluminum, we expect a region of anomalous surface plasmon dispersion from 750 to 850 nm. We demonstrate this with attenuated total reflection experiments in the Kretschmann configuration on aluminum layers. However, thin layers of aluminum exhibit optical properties different from bulk, and the effect is absent in very thin (<10 nm) layers. To get around this, we also measure in the Otto configuration, where aluminum losses do not affect plasmon excitation.

Prism coated with aluminum and anti-oxidation capping layer

Relaxation oscillation of the wave front tilt in a photonic free-electron laser

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Photonic free-electron lasers (pFEL) generate coherent Cerenkov radiation from electron beams streaming through the inside of a photonic crystal (Fig. 1a). To increase the output power emitted by such lasers, multiple electron beams are used, similar to combining individual gain sections in a diode laser array. In diode lasers combining gain sections can result in complex transverse phase dynamics due to a gain induced refractive index change. To investigate if such effects appear in a pFEL we study the transverse dynamics of the output wave front in a two-beam pFEL. In the case of two identical electron beams we observe a flat wave front. If we disturb one of the electron beams, Fig. 1b shows that the phase front is initially disturbed, but a flat phase front is re-established after relaxation oscillations.
The ground state of molecular hydrogen is energetically isolated from other electronic configurations and is therefore an ideal candidate for testing quantum calculations. Recently Komasa et al. [1] performed calculations of the entire ground state manifold including quantum electro dynamical (QED) and relativistic corrections. These calculations are believed to be accurate to within 30 MHz. Using the EF $^1\Sigma^+g$ – X $^1\Sigma^+g$ electronic system we perform an indirect measurement, via a two-photon transition, of the first vibrational level of the ground X $^1\Sigma^+g$ state. The measurements were performed using a narrow bandwidth Ti:Saph laser system frequency up-converted to the ultraviolet using a non-linear crystal arrangement. Calibration is achieved by referencing the seed light of our Ti:Saph laser system to a self referenced frequency comb. An accuracy of ~7 MHz can be achieved on the vibrational splitting thereby providing a stringent test of the theoretical work.

Spintronics is a field of electronics that allows manipulation and detection of spin information. A key phenomenon is spin drag: a drag caused by moving one spin state through another.

We want to study spin drag in a hydrodynamic Bose-Einstein condensate (BEC). This requires control over spin state population. By using an adiabatic passage of an RF-field and Landau-Zener crossings spin transfers can be made.

The transfer is induced by an RF-field generated by the same antenna as used for the evaporative cooling of the sodium gas. Unfortunately this does not readily work in a hydrodynamic BEC, since the coherent transfer process is interrupted by dephasing collisions. To address this problem, we will show an effective way of spin flipping.

The spontaneous decay of quantum emitters can be controlled by coupling them to plasmonic scatterers of sub-wavelength dimensions to form a “superemitter” with a super-radiantly boosted spontaneous emission rate. In contrast to deep-subwavelength metallic nanoantennas dielectric structures, like photonic crystals or microcavities, modify spontaneous emission on length scales comparable to the wavelength. We investigate both experimentally and theoretically the decay rate of a superemitter when it is immersed in a much larger background system that modulates the optical mode structure on a length scale comparable to the wavelength. In such a hybrid system the scattering strength of the antenna and thereby the unitary limit of scattering theory governs the decay rate enhancement. Surprisingly, a high quality cavity mode spoils the super-radiant enhancement provided by a strongly scattering optical antenna.
Applications of hyperspectral CARS microscopy

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For the rapid analysis of complicated heterogeneous mixtures we have developed a method to acquire and intuitively display hyperspectral coherent anti-Stokes Raman scattering (CARS) images. We use a conventional optical setup based around a synchronously-pumped optical parametric oscillator. An automated system records a series of high-resolution images at a pre-defined sequence of vibrational frequencies spanning hundreds of wavenumbers in a matter of minutes. A subsequent color-coding step projects the entire hyperspectral data set into a single two-dimensional image for easy visual analysis. We have demonstrated the capabilities of this system on samples from a wide range of disciplines, including biomedical, pharmaceutical, and food sciences, and have overcome some of the pitfalls associated with traditional multispectral CARS imaging.

Gas-phase infrared spectroscopy of anionic polyaromatic species

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Polycyclic aromatic hydrocarbon (PAH) molecules are now widely accepted to occur abundantly in interstellar clouds. This conclusion is largely based on the comparison between interstellar infrared emission spectra and laboratory spectra of PAH compounds. Experimental spectra have been obtained for a large variety of neutral and cationic PAHs. The charge state of a PAH molecule in an interstellar cloud depends mainly on the local electron density and UV photon flux. For regions with a relatively high electron density and low UV photon flux, PAHs have been suggested to occur as negatively charged ions (anions). Here we present the first experimental infrared spectra of anionic PAHs in the critically important wavelength ranges between 6 and 16 μm and around 3 μm.
Characterization of high harmonic beams for seeding of free-electron lasers

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We study the beam characteristics of a gas-filled capillary-based high-harmonic source for seeding of the free-electron laser FERMI@Elettra. The stability requirements for seeding include pointing stability, divergence and energy jitter. These parameters are important due to the large distance between the source and the undulator where the seed needs to overlap with the electrons. Here, we report on the beam properties of high-order harmonics generated in an Argon and Xenon-filled capillary, driven by a Ti:Sapphire laser with 35 fs pulses. We will compare our experimental results with the requirements of the FERMI@Elettra laser.

High-resolution phase and amplitude modulation using digital micromirror devices

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Spatial light modulators provide control over the propagation of light through scattering materials [1,2]. Micromirror-based spatial light modulators offer many advantages over other types, such as very high speed [3], high resolution and the ability to operate in a wider wavelength range. We demonstrate a new high-resolution modulation technique that offers a high level of control over both phase and amplitude (see Figure 1) using a digital micromirror device.


Figure 1: Field control for a single micromirror pixel and a 4x4 macropixel.
**Dissociation reactions of peptides with glutamine or asparagine residues**

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Determining the molecular weight of dissociation products of protonated peptides in a tandem mass spectrometer and matching these values with those derived from DNA databases is currently the most common method to sequence peptides and proteins, thus forming one of the cornerstones of proteomics and molecular cell biology research. While the practical application of mass spectrometry based peptide sequencing is thus widely applied in biochemistry, fundamental knowledge on the reaction mechanisms underlying the dissociation of protonated peptides remains under much debate. Here we use a combination of tandem mass spectrometry and infrared laser spectroscopy to unambiguously identify the molecular structures of fragment ions formed in the dissociation reactions. In this contribution we focus on the anomalous structures formed for peptides containing glutamine and asparagine residues.

**Laboratory study of Rayleigh-Brillouin scattering in air for measuring the winds of the Earth**

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Previously, an experimental study was carried out to determine the Rayleigh-Brillouin (RB) scattering line shape in air and in different gases for a range of pressures between 0.3 and 3 bar and at stably controlled temperatures from -30 °C to 70 °C, and at 366 nm and 90 degree scattering angle [1]. The measurements demonstrated the high signal-to-noise ratio achievable and residuals with respect to the theoretical model at the 1% level at the peak amplitude of the scattering profile. To further test the model, new setup has been built for 407 nm, with preliminary results obtained. This project is intimately connected ESA’s ADM-Aeolus mission, aiming at establishing the global wind profile over the Earth.

Highly unsaturated carbon chain radicals have attracted much interest because of their importance in combustion chemistry, in plasma processing, and in interstellar medium. The electronic origin band spectra of D- and $^{13}$C-substituted C$_{2n}$H (n=4 - 6) radicals have been recorded in direct absorption by cavity ring-down spectroscopy. D- or $^{13}$C-substituted C$_{2n}$H radicals are generated in a supersonically expanding hydrocarbon plasma by discharging acetylene (C$_{2}$D$_{2}$ or $^{13}$C$_{2}$H$_{2}$) diluted in helium. These absorption bands are assigned as the B$^{2}$Π-X$^{2}$Π electronic origin band transitions of D- and $^{13}$C-substituted C$_{2n}$H (n=4 - 6). Because of substantial lifetime broadening, rotational structures cannot be resolved in all observed bands. Isotopic effect in the B$^{2}$Π-X$^{2}$Π electronic transition of C$_{2n}$H (n=4 - 6) is also discussed.

A well-established method for elucidating structural properties of isolated peptides is IR spectroscopy in combination with quantum-chemical calculations. Amide I (C=O stretch) and Amide II (NH bend) vibrations have a noticeable shift upon hydrogen bonding and thus give a direct view on the 3-dimensional structure. Here, we explore the use of low-frequency modes (towards 100 cm$^{-1}$) for structural assignment. This far-IR region possibly contains direct information on the secondary structure of the peptides. We focus on two peptides, capped proline and trialanine. Their conformations are determined using the conventional Amide I and II region. The poorly investigated far-IR spectral region provides a unique opportunity to test the current theoretical tools. Therefore, the agreement between theory and experiment in the 100-1100 cm$^{-1}$ region is examined using various DFT functionals and anharmonic frequency calculations.

**Figure P26**
It is generally believed that plasmonic (metallic) structures only provide benefits for light emission when used with low quantum efficiency (QE) emitters. Herein we demonstrate a very large emission increase (up to 60-fold for unpolarized emission in defined directions) using emitters with an intrinsic QE close to one. This behavior is the result of the emission of the dye into collective plasmonic resonances that arise from the coupling of localized surface plasmon polaritons to diffracted orders in arrays of nanoparticles. The collective resonances have a large spatial extension and can couple very efficiently to free space radiation due to their hybrid photonic-plasmonic character. We also demonstrate strong light emission enhancements with plasmonic systems that are transparent. Dark-state polaritons, i.e., strongly coupled light-matter waves undetected by distant observers, are responsible for this effect. Localized surface plasmon polaritons in a nanoparticle arrays strongly couple to a guided mode in a light-emitting slab beneath the array. From this coupling emerge waveguide-plasmon dressed states exhibiting far-field transparency but strong near-field interactions with light-emitters. Our results hold great promise for solid-state lighting-emitting devices, which may profit from enhanced and directional sources with negligible absorption losses.

Iron is an important element in the formation of solids in space. Gas phase spectroscopy of interstellar iron and sulfur shows that their atomic abundance in space is strongly depleted with respect to that of hydrogen. The question arises how Fe and S become incorporated in solid material. The dominant source of sulphur in our solar system is solid FeS found in a primitive meteorite, implying a very efficient chemical pathway to convert gaseous S into solid FeS. To understand the chemistry of interstellar Fe and S we investigate the geometric and electronic structures of Fe and FeS nanoclusters. We aim to study size-selected Fe and FeS clusters employing the combination of IR spectroscopy with FELICE, UV/VIS electronic spectroscopy, and DFT calculations. Here we use ion-dip spectroscopy to record the spectra. Fe clusters are ionized using tunable UV laser radiation. Prior to the ionization laser pulse, the clusters are irradiated by FELICE. If the IR radiation is resonant with a transition, a depletion in the produced number of cluster ions is observed. By recording the number of ions as a function of the IR wavelength the IR spectrum is obtained.
We have experimentally studied the decay of a BEC of metastable \(^{4}\text{He}\) atoms in an optical dipole trap, for atoms in the \(m=+1\) and \(m=-1\) magnetic substates and up to a magnetic field of 450 G [1]. Our measurements confirm long-standing calculations of the two-body loss rate coefficient that show a strong increase above 50 G. We have obtained a three-body loss rate coefficient of \(6.5(0.4)_{\text{stat}}(0.6)_{\text{sys}} \times 10^{-27} \text{ cm}^6\text{s}^{-1}\), which is interesting in the context of universal few-body theory.

In the regime where two- and three-body losses can be neglected, the total number of atoms decays exponentially with time constant \(\tau\). However, the thermal cloud decays exponentially with time constant \(4\tau/3\) and the condensate decays much faster, and non-exponentially [2]. We have observed this behavior [3], which should be present for all BECs in thermal equilibrium with a considerable thermal fraction.

Gray-tone lithography implementation of Drexhage’s method for calibrating radiative and nonradiative decay constants of fluorophores

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FOM Institute AMOLF

We present a straightforward method to realize non-planar dielectric structures with a controlled height profile for use in calibration of fluorophores. Calibration of fluorescence quantum efficiency and intrinsic (non)radiative decay rates of emitters is possible by using changes in the local density of optical states, provided one can control the emitter surface distance with nanometer accuracy. We realize a method that is accurate yet fast to implement. We fabricate dielectric wedges (4 mm×4 mm×2 µm) by gray-tone UV-lithography. Its applicability as dielectric spacer is demonstrated in Drexhage experiments for three different emitters in the visible and near-infrared wavelength regime. We observe a decay-rate dependence of their fluorescent state on the distance to a silver mirror and extract quantitative values for (non)radiative decay rates and quantum efficiencies.

A multi-beam photonic Free-Electron Laser

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A photonic free-electron laser (pFEL) uses free electrons streaming through a photonic crystal (PhC) to generate tunable coherent radiation. Operation in different spectral regions can be obtained by scaling the lattice period while keeping the electron velocity the same. Increasing both the transverse dimension and the number of distributed electron beams increases the output power and results in a higher quality factor $P_F^2$. Here, we consider a pFEL driven by a set of low energy (~ 10 keV), low perveance (< 0.1 µP) electron beams. A simple and robust PhC structure is used to slow down the phase velocity (match to electron velocity) of a co-propagating electromagnetic wave. Using a particle-in-cell code, we numerically study the dynamics and calculate the small-signal growth rate and output power of the various modes. We will also present results on the scaling with the number of electron beams and electron beam current.
Hopping of dipolar excitation on a lattice of Rydberg atoms

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Lattices of atomic microtraps on permanent magnetic surfaces open up the practical possibility of creating two-dimensional arrays of Rydberg atoms [1]. Such Rydberg lattices can be viewed as a grid of potentially large electric dipoles, which can be engineered into arbitrary geometries, such as square, triangular, or more exotic configurations. In addition, within the bounds of current nanofabrication technology, the spacing of lattice sites can be chosen at will. Such a system can provide a flexible testbed for the propagation of dipolar excitations in periodic or quasi-periodic media [2].

Using correlation methods, we study the coherent diffusion of dipolar excitations in one- and two-dimensional systems of resonantly interacting dipoles. Phenomena we are interested in investigating include localization effects in a lattice with disorder, geometric frustration, and the role of vacancies and boundaries.


Magnetic lattice atom chips for quantum information science

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Quantum simulators can be implemented with neutral atoms in a periodic array [1]. Lattices formed by magnetic potentials offer significant technological advantages. Using lithographically patterned magnetic film layered on the silicon substrate, arbitrary lattice configurations and site separations can be realized. I will present our new 10 µm-period magnetic lattice atom chip, particularly in the context of implementing a scalable quantum information platform. As we have already previously demonstrated a working microtrap array [2], the major questions we are currently addressing can be summarized as “the physics of scaling down”.

One-dimensional (1D) gases exhibit interesting phenomena that are not present in either 2D or 3D. Atom chips offer an attractive route to creating and manipulating such 1D gases. By employing specifically designed wire patterns, the magnetic trapping potential of our chip features a strong harmonic confinement in the radial direction, that can be combined with a box-like confinement along the axial direction. The resulting homogeneity of the atomic density along the 1D axis allows a closer comparison to exact theoretical treatments, without the need for the local-density approximation.

Another way to tailor the axial behavior is to add an optical potential along the length of the cloud. As an initial step in this direction, we demonstrate and characterize Bragg scattering of a Bose-Einstein condensate off an optical lattice applied along the long axis of the cloud.

The prospects of reaching and characterizing the strongly interacting regime by reducing the density are investigated.

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The spatial degree of freedom of entangled photons is a resource that turns out to be one of the most promising systems for investigation of high dimensional quantum entanglement. Such systems are interesting in quantum cryptography but also show promise for the study of complex quantum dynamics as found for instance in a quantum measurement process. A prerequisite is the ability to perform high fidelity and high efficiency projective measurements on the individual photons. Spatial light modulators are the method of choice, however, they are limited to phase-only modulation if efficiency is relevant. We present a novel approach by combining the traditional concept of ‘analogue’ transverse optical modes with methods known from coding of binary data. This turns out to be very intuitive and simple; we demonstrate control over a 100x100 dimensional entangled Hilbert space experimentally and show a first application.
Optical scattering from a single particle is not always as simple as it seems. Although exact general solutions exist for spheres and infinitely-long cylinders, the problem is more complicated for partially-confined 2D geometries. We address the problem of scattering from a single cylindrical hole in a non-absorbing single-mode dielectric slab, investigating its dependence on slab thickness and hole radius and its relation to dipole emission in a confined geometry.

This theoretical study is a first step toward experiments on multiple scattering in 2D and 3D media and its effect on the optical local density of states (LDOS), the associated atom-field coupling (Purcell effect), and its potential for optical localization. Within this program, we plan to use scattering elements to modify the LDOS and thereby optimize the atom-field interaction in particular in optical devices like LEDs and solar cells.
Computational modeling of charge injection, transport and exciton generation in OLEDs

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Unique features of organic light-emitting diodes (OLEDs) in lighting applications are their large-area emission and flexibility. However, their efficiency and stability still has to be improved to make them commercially competitive. To obtain a systematic improvement in the device performance of white emitting OLEDs, the important parameters dominating the device characteristics have to be determined. Predictive computational modeling is becoming essential to save development time and effort. We present a three-dimensional Monte-Carlo model of an OLED in which charge carriers occupy sites of a regular three-dimensional lattice, with site energies drawn from a correlated Gaussian distribution. Charge injection, transport and exciton generation are treated as hopping events on this lattice, with Miller-Abrahams hopping rates. Coulomb interactions between charges and their images in the electrodes are taken into account. We show the results of a sensitivity analysis of the current and color balance of a multilayer white OLED to various parameters determining the hopping transport of holes and electrons in the stack.

Electromechanical control of the spontaneous emission rate of quantum dots in photonic crystal cavities

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Semiconductor quantum dots coupled to photonic crystal cavities (PCCs) provide single-photon sources for applications in quantum photonic integrated circuits. However a real-time spectral alignment of the cavity is needed. We present a novel approach for the tuning of PCCs by integrating them with a Nano-Electromechanical Structure (NEMS) made of two parallel GaAs slabs whose distance can be controlled by electrostatic forces. We demonstrate a reversible tuning (>10 nm) of cavity modes around single excitonic lines at low temperature and the electromechanical control of the spontaneous emission rate by over a factor of ten. This opens the way to fully-controlled and scalable single-photon sources on chip.

Fig 1: (a) Micrograph of the tunable PCC NEMS. (b) Photoluminescence of a cavity mode electrically tuned to excitonic lines.
New laser system for highly accurate direct frequency comb spectroscopy

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Optical parametric chirped-pulse amplification combined with high-harmonic generation can be employed to transfer the high accuracy of a frequency comb laser to the extreme ultraviolet (XUV) [Kandula et al., PRL 2010]. The method uses only two pulses from a frequency comb, and its accuracy depends mainly on two things: the time delay between the pulses, and the stability of the phase difference between the pulses. We present a new laser system that enables to increase the pulse delay from previously 10 nanoseconds to many hundreds of nanoseconds, and possibly microseconds. It is based on a new type of pump laser for the parametric amplifier. The new system keeps the phase of the parametrically amplified comb laser pulses constant within 10 mrad as a function of pulse delay. This combination of properties has the potential to enable kHz-level accuracy in the XUV, which we intend to use for improved measurements of the ground state ionization potential of helium atoms and hydrogen molecules.

Lorentz invariance on trial in the weak interaction

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One of the most fundamental principles on which our current understanding of nature is based is the invariance of physical laws under Lorentz transformations. Theories trying to unify the Standard Model with Quantum Gravity may break this invariance, and dedicated high-precision experiments at low energy could be used to reveal such suppressed signals from the Planck scale.

In the framework of the TRIµP (Trapped Radioactive Isotopes: micro-laboratories for fundamental Physics) program at KVI, we will test Lorentz invariance searching for a dependence of the decay rate of spin-polarized nuclei on the daily, yearly or deliberate re-orientation of the spin. Observation of such a dependence would hint at a breakdown of Lorentz invariance.

We will present results from the first experiments using $^{80}$Rb and $^{20}$Na atoms produced with the AGOR cyclotron at the KVI.
Optical transmission through hole-arrays and single holes

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Metal nano-hole arrays are known to exhibit an extraordinarily large transmission[1] and locally enhance light matter interactions[2]. We plan to use this enhancement to trap and control cold atoms. Here we present white-light transmission spectra of the structures we fabricated for these experiments. We study the transmission as a function of hole size, for a fixed array period. We investigate the positions of the transmission resonances as a function of hole size and compare this with measurements on the transmittance of single holes. Furthermore, we will report on the construction of our experimental apparatus to trap atoms close to the structures.


Experimental setup for exciting 40Ca+ ions into Rydberg states

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Laser cooled ions in Paul traps are currently the most promising systems in quantum information science. On the other hand, highly excited Rydberg states in connection with the dipole blockade mechanism offer new possibilities in atomic physics. We aim to combine both these approaches by exciting trapped 40Ca+ ions into Rydberg states [1,2] with the objective of performing spectroscopic analysis on single trapped Rydberg ions including their dynamics in a Paul trap potential. In addition, as a long term goal we want to observe the dipole blockade between Rydberg ions which would also offer a new mechanism for many body entanglement in ion crystals.

Experimentally, we trapped 40Ca+ in a linear Paul trap and excited them into the metastable 3D5/2 state from which they could be excited into Rydberg states via a 123 nm laser transition.

Spectral diffusion of single Dibenzoterrylene molecules in 2,3-dimethylanthracene

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We have studied single dibenzoterrylene molecules embedded in a dipolar disordered crystal, 2,3-dimethylanthracene, at 1.25 K. We observed broad linewidths (about 1 GHz, ~30 times broader than in anthracene crystal), high saturation excitation intensities (~1,000 times larger than in anthracene), as well as strong spectral diffusion. Spectral jumping was studied for varying excitation intensity and temperature. We propose that spectral diffusion and dynamic disorder in this system arise from the combination of static disorder with slight reorientations of the methyl groups of the host molecules.

High-resolution spectroscopy on the A-X band of CO for probing possible $\mu$-variation

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The $^1\Pi - ^1\Sigma$ transitions of carbon monoxide (CO) have been detected in six highly redshifted quasar systems. We identify this as a novel probe system to derive constraints on possible temporal and spatial variations of proton-to-electron mass ratio ($\mu$) over cosmological timescales. For this purpose, high-resolution absorption spectroscopy of A-X ($v, 0$) bands for $v=0-9$ have been performed using the VUV Fourier-transform facility at the Soleil synchrotron with an accuracy of $\Delta \lambda / \lambda = 3 \times 10^{-7}$. For confirmation of the absorption data, two-photon Doppler-free laser spectroscopy has been employed for the $(0,0)$ and $(1,0)$ bands at the $3 \times 10^{-8}$ accuracy level. Furthermore, the sensitivity coefficients of the transitions to a change in $\mu$ have been derived. A perturbation analysis of the $^1\Pi$ level energies has been performed for $v=0-9$ bands.

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Imaging is an essential tool in several fields, including lithography and the structural analysis of proteins. By using shorter wavelength sources, a higher resolution can be achieved. For this purpose, a significant amount of research is aimed towards the construction of soft X-ray sources and the necessary lensless imaging techniques.

We are developing a laser system for the generation of spatially coherent water-window ($2.3 - 4.4$ nm) X-ray pulses using high-harmonic generation. Femtosecond pulses will be amplified to $10 \text{ mJ}$ in an optical parametric chirped pulse amplification scheme. This is pumped by a Nd:YAG based system which produces $100 \text{ mJ}$ pulses. The high gain and reduced thermal effects of quasi-CW diode-pumped Nd:YAG crystals allow operation at $300 \text{ Hz}$.

The available soft-X-ray flux can be used much more efficiently by employing a new broadband imaging technique, which obviates the need for a monochromator. By using two pulses separated in time, it is possible to spectrally resolve diffraction patterns. Using phase-retrieval methods, these quasi-monochromatic diffraction patterns can then provide high-resolution images throughout the entire source spectrum.
SEGA mode locking, first experimental indications of operation

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We present an alternative scheme for laser mode-locking and discuss its first experimental indications of operation. In this scheme, a large set of spatially separated gain (SEGA) media generate single-frequency continuous-wave (CW) light beams arranged as an approximately equidistant spectral frequency comb. After combining the beams, a common saturable absorber causes mutual phase locking. As a result, a fully equidistant frequency comb, and ultra short pulses with extremely high repetition rates and high average output power are expected. The set of frequencies on which the laser oscillates, and therefore the pulse repetition rate, can be controlled by resonator-internal optical elements, rather than cavity length. We examined spectral and time-resolved intensity autocorrelation properties of the SEGA laser. We observed an improved equidistance in the frequency comb and peaks in the autocorrelation. By exchanging one of the optical elements but keeping the laser cavity size equal, we observe a corresponding change of the repetition rates from 21 GHz to 69 GHz.

Quantum optics with semiconductor spin ensembles

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We present quantum optical studies with ensembles of donor-bound electron spins in ultra-pure GaAs materials with Si doping at very low concentrations (\(10^{13}-10^{14}\) cm\(^{-3}\)). These donor-bound electrons (D\(^0\) systems) provide unique system properties for solid state quantum information processing, since they combine a high level of ensemble homogeneity (as for atomic vapors) with strong optical transitions and the ability to nano-fabricate and integrate very compact optoelectronic devices with semiconductor processing tools. Specifically, we report the observation of dynamic nuclear polarization in this material \cite{1}, using electromagnetically induced transparency as a driving mechanism and as a probe for the effective magnetic (nuclear Overhauser) field.

\cite{1} M. Sladkov et al., Phys. Rev. B 82, 121308 (2010).
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In-situ mapping of 3D material flux in PLD plasmas

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Pulsed Laser Deposition (PLD) is a versatile technique to deposit complex materials. However, most knowledge on the PLD process is based solely on empirical research examining what parameters appear to provide the best result for a specific material and setup. The goal of our research is to progress towards an improved understanding and control of PLD for scaling up to large area deposition while maintaining full control on film growth, i.e., to the level of atomic precision.

We build a PLD test system that allows for in-situ Laser Induced Fluorescence (LIF) imaging, Absorption Spectroscopy and Doppler Shift measurements to map the spatial and temporal development of the ablation plasma. From this, we can generate a 3D map of the material flux towards the substrate that is essential for obtaining a fundamental understanding of the relation between the deposition parameters and the film growth. Here, we present the first results on LIF imaging of plasmas generated from TiO₂ targets.

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Studying structural dynamics using ultrafast electron diffraction

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Ultrafast electron diffraction (UED) enables the study of the dynamics of non-equilibrium structures, like phase transitions and conformation changes, with both spatial and temporal resolution at the atomic level (~0.1 nm and ~100 fs). To acquire a diffraction pattern of sufficient quality, typically 10⁶ electrons are required. So far in UED experiments, multiple shots are used to build up a high-quality diffraction pattern, limiting the applicability of UED to reversible processes. Single-shot operation requires packing ~10⁶ electrons in a single bunch. Unfortunately, the strong repelling Coulomb forces inevitably broaden the bunch.

In our setup, we accelerate electron bunches to 100 keV and reverse the bunch expansion by injection onto the oscillatory field sustained in a radio-frequency (RF) cavity. In this way, we have realized sub-100 fs, 100 fC, 100 keV electron bunches, which thus fulfill all requirements for single-shot femtosecond electron diffraction. Using only a single electron bunch, we have demonstrated single-shot diffraction on a variety of thin films.

Currently, we are carefully characterizing the bunches in our setup and we are working on pump-probe time-resolved UED experiments.
Narrow bandwidth optical frequency references for high-accuracy extreme ultraviolet spectroscopy

LaserLaB, Department of Physics and Astronomy, VU University Amsterdam

Ultra-stable optical frequency references will be the bases for the enhancement of several high-precision frequency comb laser metrology experiments at LaserLaB Amsterdam[1,2,3]. A semiconductor based CW laser system with a target bandwidth of 1 Hz at ~1550 nm is under development. Amplification, frequency conversion and distribution stages cover the wavelength ranges of our Er and Yb fibre and Ti:sapphire frequency comb lasers. Some features of the system are in-house developed diode-laser drivers (modulation bandwidth > 1 MHz) and fibre-integrated C-band beat units. We have partly characterised the narrow bandwidth CW lasers and were able to determine an upper limit on the local measurement noise floor at an Allan deviation of <5(4).10^{-18} at 1 hour. Doubling of the CW laser and optical locking of the Ti:sapphire laser used for high-accuracy XUV spectroscopy is currently under development.

[2] FOM program 125: Broken Mirrors and Drifting Constants

Frequency comb generation by CW laser injection of a hybridly mode-locked quantum-dot laser

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Robust integrated semiconductor-based optical frequency combs can pave the way to a wider application of frequency comb technology in metrology and telecommunication applications. InAs/InP(100) quantum-dot lasers (QDL) operate in the 1.55 μm wavelength range and have broad gain bandwidth suitable for sub 100 fs pulse generation. We report on the observation of dynamics in a hybridly mode-locked quantum-dot laser under continuous-wave laser injection. Comb generation was possible in and outside the QDL output spectrum. The generated comb has been characterised in terms of signal to background of its modes and the mode coherence, resulting in Hz level accuracy. This research contributes to the understanding of QDL device physics and shows that the quantum-dot material does not pose significant limitations to the coherence of the generated comb. To reach the ultimate goal of fully integrated quantum-dot frequency comb lasers, self-referencing and absolute mode stabilisation techniques still have to be investigated.
SuperGPS through optical networks

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Global Navigation Satellite Systems (GNSS) such as GPS are essential for positioning and the dissemination of Coordinated Universal Time (UTC). The GNSS principle of operation relies on the accurate synchronization of GNSS satellites, realized by on-board atomic clocks, and the transmission of radio signals for positioning and timing. Thus, GNSS provide network synchronization for wide-area technologies such as mobile telecommunications and power grids. In view of current trends towards more intricate optical networks with increased data transfer rates, optical timing distribution may offer certain advantages over GNSS. These include higher attainable accuracy and absence of typical GNSS limitations such as atmospheric disturbances and signal interference. Using a 2×317 km SURFnet optical telecommunication fiber link between VU and KVI, we demonstrate long-distance frequency transfer with stability two orders of magnitude better than standard GPS performance. Ultimately, the fiber link may allow remote comparisons of optical clocks for fundamental physics tests.

Decelerating and trapping ammonia molecules in a ring decelerator

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2 Kernfysisch Versneller Instituut, Groningen

We present deceleration, trapping and cooling of ammonia molecules by a moving electric potential. This potential is created by a Stark ring decelerator, comprising a series of ring-shaped electrodes to which oscillating high voltages are applied. By lowering the frequency, the molecules confined in the moving trap can be decelerated to any velocity or brought to a standstill. As the molecules are confined in a ‘true’ 3D well, this new kind of deceleration has practically no losses. The necessary voltages are generated by amplifying the output of an arbitrary wave generator using 8 fast HV-amplifiers, giving us great control over the phase-space distribution of the trapped molecules.
We discuss the latest progress of our experiments with atomic microclouds on a magnetic-film atom chip [1]. We discuss our recently installed next-generation chip hosting square and triangular lattices with 10 µm trap spacing. This is aimed at realizing individually addressable qubits using the Rydberg dipole blockade in mesoscopic ensembles. Similar Rydberg-Rydberg interactions between different microclouds should allow controllable qubit-qubit interactions. We present our improved imaging setup aiming for single-atom detection sensitivity. By scaling down even further, we also aim for direct quantum simulators using sub-optical lattices of 100 nm period[1] in a variety of geometries, including graphene and Kagome lattices.

**Electric dipole moments in heavy atomic systems**

**Bodhaditya Santra**, Klaus Jungmann, Lorenz Willmann, Hans W. Wilschut  
*KVI, University of Groningen*

**Abstract**

Permanent electric dipole moments (EDMs) violate simultaneously the two discrete symmetries parity (P) and time-reversal (T) and are strongly suppressed in the Standard Model (SM). Thus any observation of an EDM at the present level of sensitivity in one of the many different experiments worldwide would imply CP-violation beyond the SM. Of particular interest are EDM searches in compound systems like nuclei, atoms or molecules which experience enhancements scaling as the third power of the atomic number Z. Atomic radium will be discussed in comparison to other systems. The sensitivity of radium arises from its nuclear and atomic structure. As a result radium offers the largest known atomic enhancement factors to nuclear and electron EDMs. The enhancement factors depend on atomic states. They are particularly large for metastable D-states. The experimental exploitation requires sources of radium, the preparation of laser cooled and trapped samples and a sensitive detection method. These issues will be discussed in view on the atomic physics aspects of the sample preparation.

**Ultrafast fluorescence quenching of porphyrin in graphene-porphyrin hybrid material**

**Divya Sharma**¹, Xiaoyan Zhang², Ben L. Feringa², Wesley R. Browne², Jennifer L. Herek¹  
¹University of Twente, MESA+ Institute for Nanotechnology, The Netherlands.  
²University of Groningen, Stratingh Institute for Chemistry, The Netherlands

**Abstract**

Graphene-based hybrid nanomaterials, which combine the unique properties of each component, have the potential of finding diverse applications in solar cells, sensors and catalysis. Here, we report time-resolved absorption spectroscopic studies on such a hybrid material (consisting of porphyrin molecules covalently attached to graphene) to resolve the mechanism (energy or electron transfer) underlying the reported [1] fast quenching (< 500 ps) of the porphyrin singlet excited state.

P61

Polarization-resolved phase-sensitive near-field microscopy on photonic-crystal waveguides

A. Singh¹, S.R. Huisman¹, J.P. Korterik¹, F.B. Segerink¹, J.L. Herek¹, A.P. Mosk¹, S. Stobbe², A. Lagendijk¹,³, P. Lodahl², W.L. Vos¹, P.W.H. Pinkse¹

¹ MESA+, University of Twente, The Netherlands
² Niels Bohr Institute, Denmark
³ AMOLF, The Netherlands

Near-field scanning optical microscopy (NSOM) is a powerful technique for studying light transport in photonic-crystal waveguides. We have performed high resolution spectral and spatial scans using phase-sensitive NSOM to extract mode profiles and bandstructures [1]. Our results demonstrate Anderson-localized modes near the band edge, caused by intrinsic disorder in the waveguide [2]. We have upgraded the setup to perform polarization-resolved near-field mapping as shown in figure 1.


Fig. 1: a) and b) are amplitudes of orthogonal polarization components measured simultaneously.

P62

Selectively exciting Fabry-Perot cavity modes with a spatial light modulator

G.B. Spenkelink, M. Peters, S.A. Goorden, A.P. Mosk, and P.W.H. Pinkse

MESA+ Institute for Nanotechnology, University of Twente

Optical resonators are essential in most lasers, metrology, trace-gas detection methods and fundamental studies, such as on geometric phases [1] and optical cooling and trapping [2]. In these applications, control over the resonator’s spatial modes is important but usually limited to one transverse mode. Flexible access to higher-order modes would offer important advantages in studies such as [1,2]. Here we experimentally demonstrate selective excitation of a whole family of transverse modes (see Figure 1) of a Fabry-Perot cavity using a micro-mirror-based spatial light modulator to shape the wavefront of the cavity excitation beam.


Figure 1: Measured examples of transverse Laguerre-Gaussian cavity modes. Numbers indicate Laguerre-Gaussian mode indices.
Absorption by molecular oxygen around 922 nm

Frans. R. Spiering and Wim J. van der Zande
Radboud University Nijmegen,
Institute for Molecules and Materials

Molecular oxygen is special, having a number of low lying electronic states that are coupled to the ground state with very weak transitions. Even in spite of the large amount of molecular oxygen in our atmosphere, part of the sun light shining through the atmosphere, with wavelengths corresponding to these transitions, reaches the surface of the earth. However, a collision partner, for example another O₂ molecule or an N₂ molecule, can induce a transition moment in oxygen during a molecular collision. This collision induced absorption is only a weak source of direct heating of the atmosphere.

Using cavity ring-down spectroscopy, we measured the collision induced absorption resulting from the \( a^1\Delta_g(v=2) \leftarrow X^3\Sigma_g^-(v=0) \) transition. From these measurements, we show that vibrational quanta influence the absorption in an unexpected way. Furthermore, the measurements allow us to estimate the heating due to this transition.

Controlling individual nuclear spins in diamond with a single electron spin

T.H. Taminiau¹, J.J.T. Wagenaar¹, T. van der Sar¹, F. Jelezko², V.V. Dobrovitski³, R. Hanson¹
¹ Kavli Institute of Nanoscience,
Delft University of Technology
² Institut fur Quantenoptik, Universitat Ulm
³ Ames Laboratory and Iowa State University

Detecting the weak magnetic moment of the nuclear spin of a single atom presents the ultimate sensitivity limit in magnetic resonance imaging. However, addressing a single nuclear spin is challenging because it is generally embedded in a noisy environment such as a bath of surrounding nuclear spins.

We use the electron spin of a nitrogen-vacancy (NV) center, which can be measured optically, to detect and control individual nuclear spins in diamond [1, 2]. We amplify the weak signal of a specific nuclear spin with a resonant multi-pulse sequence, which at the same time decouples the electron spin from all other nuclear spins [2]. Our results can enable tomography with single nuclear spin sensitivity and greatly extend the number of solid-state qubits available for quantum information processing.

Characterization of a cluster jet for quasi-phase matching of high harmonic generation

Y. Tao¹, S.J. Goh¹, P.J.M. van der Slot¹, H.J.M. Bastiaens¹, S. Franzen⁵, R.Hagmeijer⁵, S.G. Biedron⁴, M.B. Danailov², S.V. Milton⁴, J. Herek³, K.J. Boller¹

¹ Laser Physics and Nonlinear Optics
² FERMI@Elettra, Trieste, Italy
³ Optical Sciences, Mesa+ Institute for Nanotechnology
⁴ Colorado State University, Colorado, USA
⁵ Department of Mechanical Engineering, University of Twente, The Netherlands

We investigate the possibility to realize a fully coherent light source emitting XUV down to a wavelength of 4 nm by using high harmonic generation (HHG). The source will be based on ions rather than on neutral atoms as used in a standard approach. Due to ionization of the generating plasma medium, current phase-matching techniques applied to HHG in neutral gases are not suitable. Instead, we will investigate quasi-phase matching (QPM) and wave guiding over an extended interaction length to increase the output pulse energy. For this, we will ionize a density modulated cluster jet to prepare a plasma waveguide for the drive laser with an appropriate density modulation along its axis for QPM.

Here we report on the initial characterization of the argon cluster jet that at a later stage will be modulated. We employ Rayleigh scattering imaging combined with interferometry to infer the cluster size, and the cluster and gas density distribution in the jet. The results will be compared to calculations with a quasi-one-dimensional fluid dynamics model.

Doppler-free electromagnetically induced transparency with Rydberg Atoms in Electric Fields

Atreju Tauschinsky, Richard Newell, Vanessa Leung, Robert Spreeuw, and Ben van Linden van den Heuvel

Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam

We study rubidium Rydberg states in static and oscillating electric fields using Electromagnetically Induced Transparency (EIT) in the 5s-5p-nl system for \( n \geq 28 \) and \( l = 0...2 \). We present high-precision Doppler free measurements of DC Stark shifts in a room temperature vapour cell. These results are in excellent agreement with theoretical calculations. They clearly show that the assumption of quadratically shifting energy levels where the shift is determined by the polarizability of the state is valid only for very small fields, less than \( \approx 5\% \) of the Inglis-Teller Limit. We furthermore observe \( l=1 \) states the excitation of which is dipole-forbidden in zero field, as well as crossings with high-\( l \) manifold states for \( l=0 \) Rydberg states. We finally investigate the behaviour of Rydberg states in superposed AC and DC electric fields and observe populated high order radio-frequency sidebands of the Rydberg states.

Stark Spectroscopy on state 2Bd

\[
\text{Energy (MHz)} \quad \text{Field (V/cm)}
\]

Stark Spectroscopy on state 2Bd

![Stark Spectroscopy on state 2Bd](image)
Quantum-coherent coupling of light to micromechanical motion

E. Verhagen\textsuperscript{1,2}, S. Deléglise\textsuperscript{1}, S. Weis\textsuperscript{1}, A. Schliesser\textsuperscript{1}, and T.J. Kippenberg\textsuperscript{1}
\textsuperscript{1} EPFL, Switzerland
\textsuperscript{2} present address: FOM-Institute AMOLF

A route to controlling the quantum states of macroscopic mechanical oscillators is to exploit the radiation-pressure coupling between optical and mechanical degrees of freedom in suitably engineered optical cavities. If the coherent coupling rate exceeds both the optical and the mechanical decoherence rate, quantum states are transferred from the optical field to the mechanical oscillator and vice versa, thus allowing optical control of the mechanical oscillator state. We experimentally demonstrate such quantum-coherent coupling between optical photons and a micromechanical oscillator in a silica toroidal micro-resonator embedded in a He-3 cryostat. The mechanical oscillator is laser cooled close to the quantum ground state, with an average occupancy of 1.7±0.1 phonons. These results establish an efficient quantum interface between mechanical oscillators and optical fields.


Hindered internal rotation as a probe for drifting constants

Paul Jansen\textsuperscript{1}, Isabelle Kleiner\textsuperscript{2}, Li-Hong Xu\textsuperscript{3}, Wim Ubachs\textsuperscript{1}, and Hendrick L. Bethlem\textsuperscript{1}
\textsuperscript{1} LaserLaB, VU University Amsterdam
\textsuperscript{2} LISA, CNRS UMR, Universités Paris 7 et Paris Est
\textsuperscript{3} Department of Physics and Centre for Laser, Atomic, and Molecular Sciences, University of New Brunswick

Recently, we identified methanol (CH3OH) as a sensitive probe for variations of the proton-to-electron mass ratio $\mu$. The origin of the high sensitivity of methanol can be found in the hindered rotation of the molecule – i.e. transitions that convert internal rotation into overall rotation give rise to enhancement of the sensitivity of the particular transition. As internal rotation is a common phenomenon in polyatomic molecules, it is likely that other molecules display similar or even larger effects. Here we generalize the concepts that form the foundation of the high sensitivity in methanol and use this to construct a toy model which can aid the identification of other internal rotors with possibly sensitivity. This model will be tested by applying it to other molecules that exhibit hindered internal rotation. From this analysis it follows that methanol is probably the most suitable candidate for cosmological tests.
Lensless imaging using ultra-broadband light sources

Stefan Witte, Vasco Tenner, Daniel Noom, Kjeld Eikema
LaserLaB, Vrije Universiteit Amsterdam

Lensless imaging is an approach to microscopy that essentially replaces the microscope optics by computer algorithms. It can be especially powerful in cases where lenses are not readily available, such as for the development of soft-X-ray microscopes. Coherent table-top soft-X-ray source development has seen major progress recently. However, these sources have intrinsically ultra-broadband spectra, while lensless imaging methods require monochromatic light. We have developed a method that allows efficient lensless imaging with ultra-broadband light sources. Our approach is based on Fourier-transform spectroscopy, using coherent pulse pairs for diffractive imaging, and enables us to reconstruct spectrally-resolved images throughout the entire source bandwidth. Furthermore, we have developed methods for robust and rapid image reconstruction from the recorded diffraction patterns, as a major step towards efficient table-top X-ray microscopy.

Laser-cooled atomic beam ion source

Department of Applied Physics, Eindhoven University of Technology
PO Box 513, 5600 MB Eindhoven, Netherlands

A new type of high-brightness ion source is under development which employs transverse laser cooling and compression of a thermal atomic Rb followed by photo-ionization. The source should be compact enough to fit on an existing Focused Ion Beam instrument. Simulations of a 10 cm long cooling stage and of disorder-induced heating of the resulting ion beam, predict an achievable brightness for $^{87}$Rb$^+$ of order $10^7$ A/m$^2$ sr eV at an energy spread of less than 1 eV and a current of tens of pA, which is substantially better than conventional ion sources. Experimental realization of the compact ion source has recently started with the development of an efficient high-flux atom source.
Nanoplasmonics beyond the refractive index

M. Wubs, G. Toscano, S. Raza, W. Yan, N. Stenger, S. Xiao, A.P. Jauho, N. A. Mortensen
Technical University of Denmark

Tiny metal nanostructures are used to guide, concentrate, and enhance light on subwavelength scales. Strongly enhanced light-matter interactions enable plasmonic sensing and single bio-molecule detection. The optical fields are usually computed by describing the metal in terms of its refractive index, but this no longer works for typical sizes below 10 nm. For arbitrarily shaped plasmonic nanostructures in that regime we present instead hydrodynamic calculations, where the internal kinetics of the free electrons is described by a pressure term. This introduces a new length scale into nanoplasmonics, makes the metal response nonlocal, with important consequences for field enhancements, for example finite optical fields even near infinitely sharp metal tips (see figure). We discuss far-field scattering and near-field enhancement for particles, dimers, and surfaces.

New materials for quantum optics with spins and defects in semiconductors

Olger V. Zwier1, A. R. Onur1, C. Kruse2, D. Hommel2, C. H. van der Wal
1 Zernike Institute for Advanced Materials, University of Groningen
2 Institute for Solid State Physics, University of Bremen, Germany

Spins and defects in semiconductors allow for combining optical control with long-lived memories for quantum states. We optically studied the coherent spin properties of ensembles of donor-bound electrons in GaAs, focusing on electromagnetically induced transparency (EIT), and electron-nuclear spin interaction. In GaAs a nuclear spin bath dephases the electron spin state in about 3 ns. We now extend this research to new materials that suffer less from such intrinsic limitations. Firstly, for donor-bound electrons in ZnSe the lattice material only has few (and can be made free of) nuclear spins, which has been shown to lead to longer coherence times [1]. This also has the potential to directly use the single nuclear spin of the donor atom. Secondly, SiC has been shown to contain deep paramagnetic defect states [2] for which we currently explore the possibility of all-optical spin manipulation.

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dr. D. van Oosten              Cold atom nanophotonics.
prof.dr.ir. H.T.C. Stoof       Dynamics of Bose-Einstein Condensates, Quantum Effects in Degenerate Fermion and/or Boson gases.

dr. R.A. Duine               Spintronics.
This meeting is organized under the auspices of the NNV-section Atomic, Molecular and Optical Physics, with financial support of the Dutch Science Foundation and the Foundation FOM.

The program is compiled by:
Giel Berden
Caspar van der Wal