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DTU Fotonik
Department of Photonics Engineering

Determination of radial quantum dot position in needle nanowires from far-field measurements

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I. Tapers for single-photon sources

- **Quantum dots embedded in tapered nanowires have been shown as good candidates for realising an efficient single-photon source [1,2].**
- **For optimal efficiency the quantum dot should be placed on-axis. In this work we want to develop, a method for determining the quantum dot position in the nanowire based on the far-field emission pattern. The modelling is done using an open-geometry Fourier modal method [3], and a near-field to far-field transformation [4].**

[1]

[2]

II. Modes and spontaneous emission rates in a nanowire

- The coupling of the quantum dot to the optical modes depends on the radial position of the quantum dot.
- Interference between the HE11 and TE01 modes leads to different power distributions in the NW, that should be visible in the far-field.

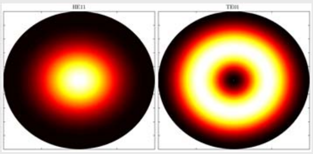

Figure 1: Mode profiles for the HE11 and TE01 modes.

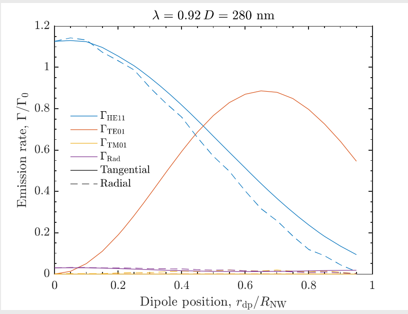

Figure 2: Spontaneous emission rate for a dipole in a nanowire.

III. oFMM and near-field to far-field transformation

- Field is expanded on eigenmodes:

$$E(r,\phi,z) = \sum_{n,j} a_{nj}(r) E_{nj}(r) \exp(in\phi) \exp(i\beta_j)$$

- Eigenmodes are expanded as a Fourier integral – open BCs:

$$E_{r,nj} = \mathrm{i}\int \left[b_{nj}^{E}(k) J_{n+1}(kr) - c_{nj}^{E}(k) J_{n-1}(k) \right] k \mathrm{d}k$$

- Far-field is computed as:

$$E_{\theta,nj,\mathrm{far}} \cong -\frac{\mathrm{i}k_0 \exp(-\mathrm{i}k_0 r)}{4\pi r} \left(L_{\phi,nj} + \eta N_{\theta.nj} \right),$$

where,

$$N_{\theta,nj} = 4(-\mathrm{i})^n \pi \cos\theta \cos n\phi \sum_m \Delta k_m \left(b_{mjn}^{H} - c_{mjn}^{H} \right) \delta(k_m - k_0 \sin\theta)$$

$$L_{\phi,nj} = 4(-\mathrm{i})^{n-1} \pi \cos n\phi \sum_m \Delta k_m \left(b_{mjn}^{E} + c_{mjn}^{E} \right) \delta(k_m - k_0 \sin\theta)$$

IV. Far-fields for needle structure

- Measured far-fields for needle with $D_{\mathrm{Bot}} = 182$ nm (to be confirmed) and NA = 0.75.
- Simulated far-fields with $D_{\mathrm{Bot}} = 200$ nm, have good agreement with measurements.
- Cut-off for TE01 mode is at $d/\lambda = 0.23$, interference is still present – how?

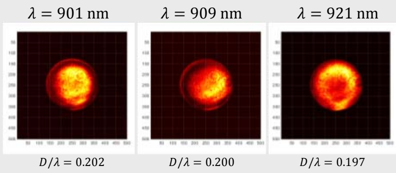

Figure 3: Measured far-fields for three different quantum dots.

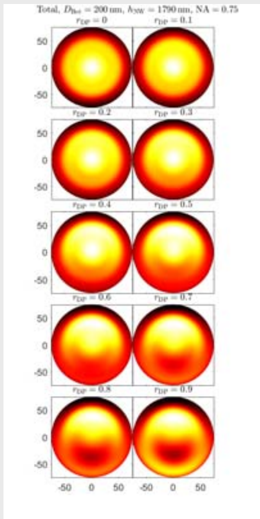

Figure 4: Simulated far-fields, where $D/\lambda = 0.22$

V. Radiation mode or guided mode?

- The guided modes exist as radiation modes just before they are guided.
- These semi-guided radiation modes will interfere with the guided HE11 mode, and only slowly escape the nanowire.
- A simple 2-mode model is therefore not enough.

Guided modes: $k_0^2 \leq \beta^2 < (nk_0)^2$
Radiation modes: $0 \leq \beta^2 < k_0^2$
Evanescent modes: $\beta^2 < 0$

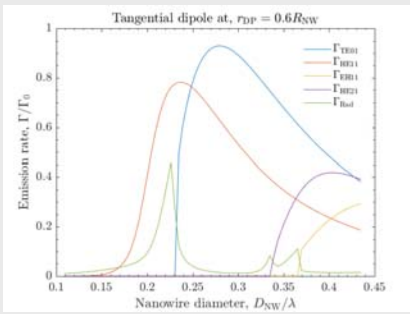

Figure 5: Spontaneous emission rate for a dipole in a Nanowire placed 0.6 R_{NW} off axis.

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