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Publication date: 2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
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].

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.

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

- Field is expanded on eigenmodes:
  \[ E(r, \theta, z) = \sum_{n, j} a_{nj}(r)E_{nj}(r) \exp(\imath n\phi) \exp(\imath j\beta) \]
- Eigenmodes are expanded as a Fourier integral – open BCs:
  \[ E_{\phi, nj} = \int [h_{nj}(k L)/(k L) + c_{nj}(k L)] \exp(\imath j\beta L) k dk \]
- Far-field is computed as:
  \[ E_{\phi, nj, far} \approx \frac{-\imath k_0 \exp(-\imath k_0 r)}{4\pi r} (L_{\phi, nj} + \eta N_{\phi, nj}), \]
  where,
  \[ N_{\phi, nj} = 4(-1)^n \pi \cos \theta \cos n\phi \sum_m \Delta k_m (h_{mj,n} + c_{mj,n}) \delta(k_m - k_0 \sin \theta) \]
  \[ L_{\phi, nj} = 4(-1)^{n-1} \pi \cos \theta \cos n\phi \sum_m \Delta k_m (h_{mj,n} + c_{mj,n}) \delta(k_m - k_0 \sin \theta) \]

IV. Far-fields for needle structure

- Measured far-fields for needle with \( D_{bot} = 182 \) nm (to be confirmed) and NA = 0.75.
- Simulated far-fields with \( D_{bot} = 200 \) nm, have good agreement with measurements.
- Cut-off for TE01 mode is at \( \lambda/5 \approx 0.23 \), interference is still present – how?

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.