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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:

\[ E(r, \phi, z) = \sum a_{n,l}(r)E_{n,l}(r) \exp(in\phi) \exp(il\phi) \]

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

\[ E_{\tau,n,l} = i \int [b_{n,l}^{HE} (k) E_{n+1,l} (kr) - c_{n,l}^{HE} (k) E_{n-1,l} (kr)] dk \]

• Far-field is computed as:

\[ E_{\theta,n,l,\text{far}} \approx -\frac{ik_0 \exp(-ik_ar)}{4\pi r} (N_{\theta,n,l} + \eta n_{\theta,n,l}) \]

where,

\[ N_{\theta,n,l} = 4(-1)^n \pi \cos \theta \cos n\phi \sum_m \Delta k m (b_{m,n,l}^{HE} - c_{m,n,l}^{HE})(k_m - k_0 \sin \theta) \]

\[ L_{\theta,n,l} = 4(-1)^n \pi^{-1} \cos \phi \cos n\phi \sum_m \Delta k m (b_{m,n,l}^{HE} + c_{m,n,l}^{HE})(k_m - k_0 \sin \theta) \]

IV. Far-fields for needle structure
• Measured far-fields for needle with \( D_{\text{Bot}} = 182 \text{ nm} \) (to be confirmed) and \( NA = 0.75 \).
• Simulated far-fields with \( D_{\text{Bot}} = 200 \text{ nm} \), have good agreement with measurements.
• Cut-off for TE01 mode is at \( \lambda/\varpi = 0.23 \), 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.