On-Chip Quantum Optics in 1D: Single Molecules Coupled via a Dielectric Nanoguide

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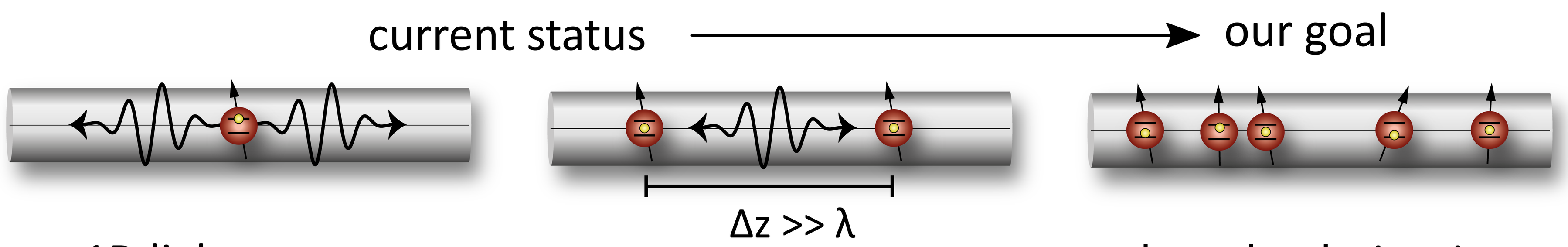
nano-optics

Introduction

One-dimensional subwavelength waveguides (nanoguides) promise efficient light-matter interactions between many emitters on length scales much longer than their transition wavelength. We report on the coupling of organic dye molecules at low temperatures to the confined mode of a TiO_2-waveguide via the evanescent field and demonstrate external control on the coupled nanoguide-emitter system via static electric fields. In future, we want to extend this approach to build up a network of many quantum emitters and study the emergence of polaritonic states [1].

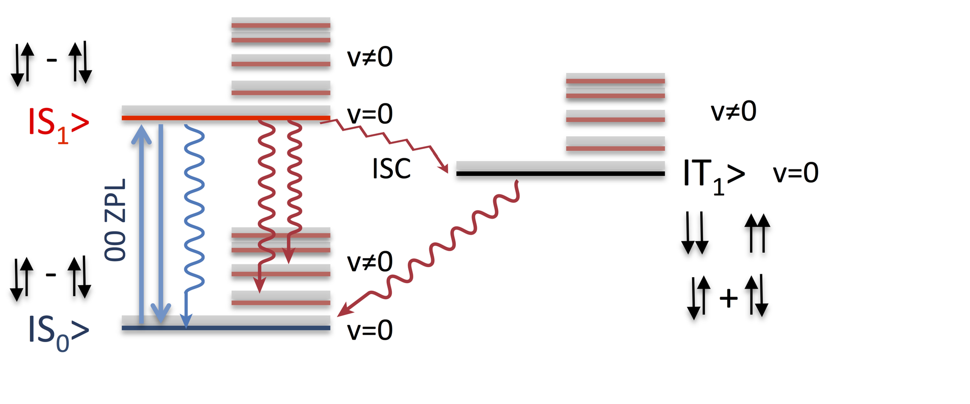


1D light matter interface

far field coupling of two emitters

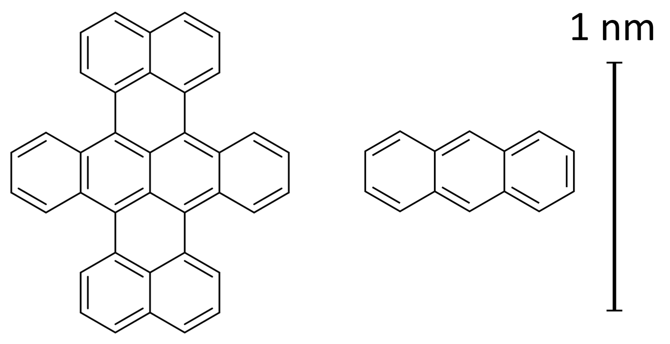
shared polaritonic excitation

Quantum Emitter: Dye Molecule

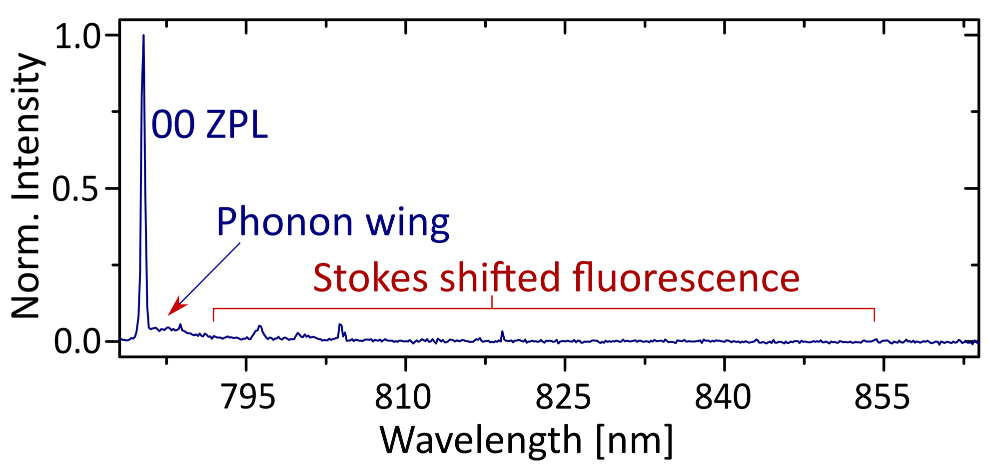


Simplified level scheme of dye molecules

host-guest system:



DBT (dye) Antracene (matrix)

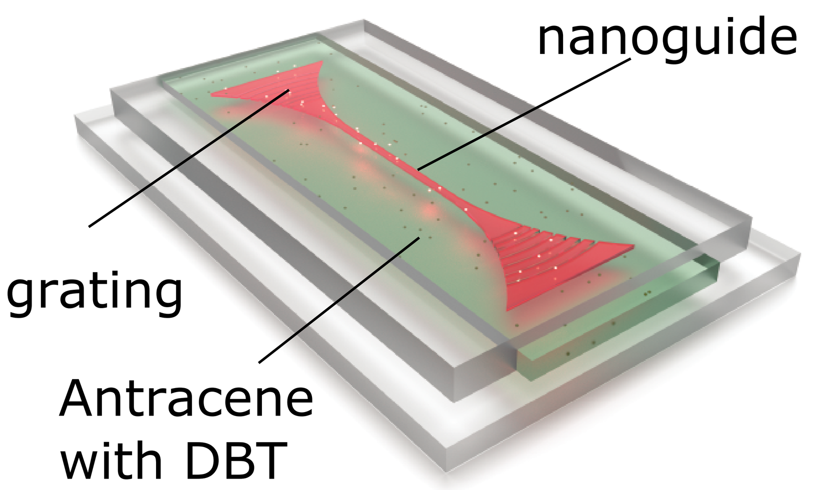


Emission from a single DBT molecule.

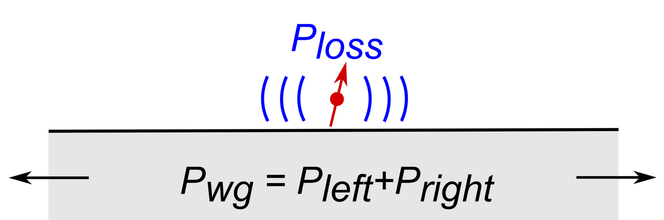
- lifetime-limited transition at 1.5 K (Γ_0 = 30 MHz)
- quantum efficiency close to unity
- emission on 00-ZPL η = 50 %

Coherent Interaction in a Nanoguide[2,3]

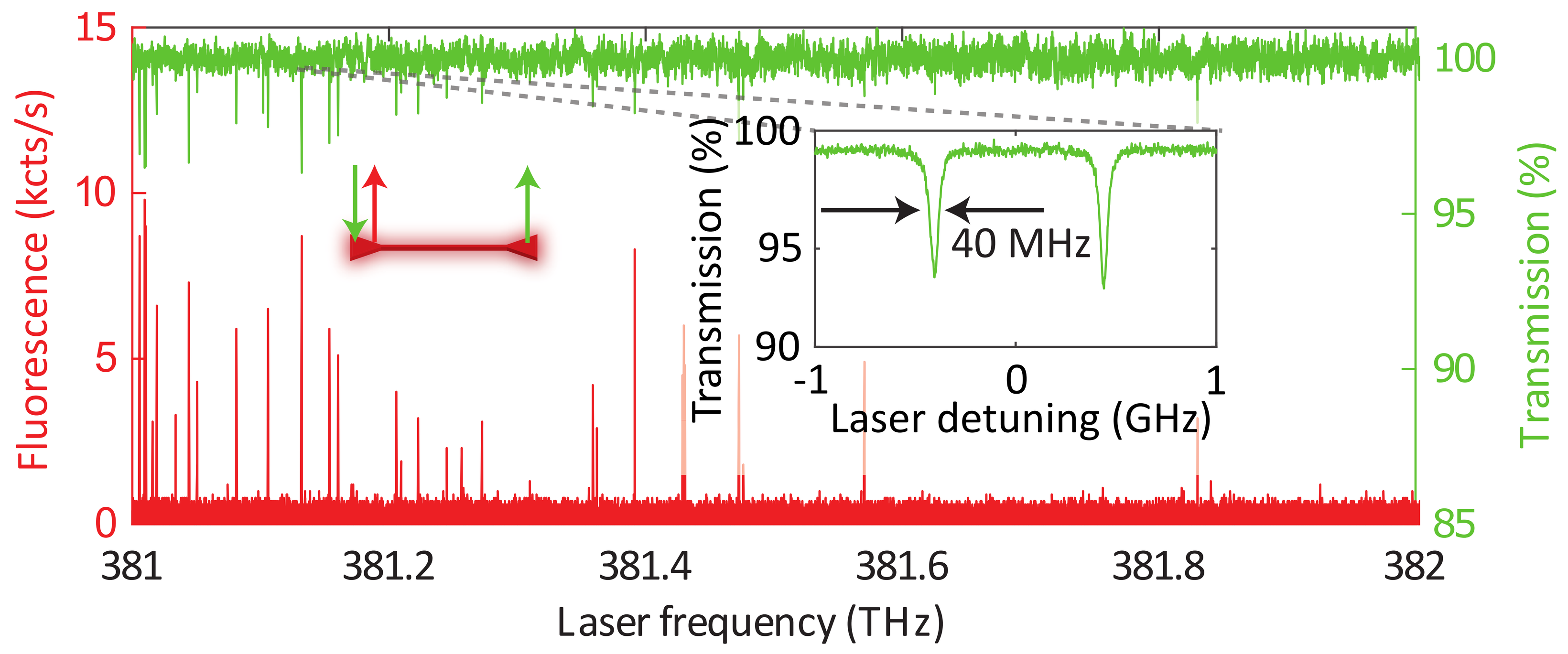
- $(200\ nm)^2$ cross section TiO_2-nanoguides
- covered by Antracene doped with DBT
- in/out coupling of the waveguide mode by grating couplers
- theoretical coupling efficiency β up to 32 %



$$\beta = \frac{P_{\mathrm{wg}}}{P_{\mathrm{wg}} + P_{\mathrm{loss}}} = \frac{\Gamma_{\mathrm{wg}}}{\Gamma_{\mathrm{tot}}}$$

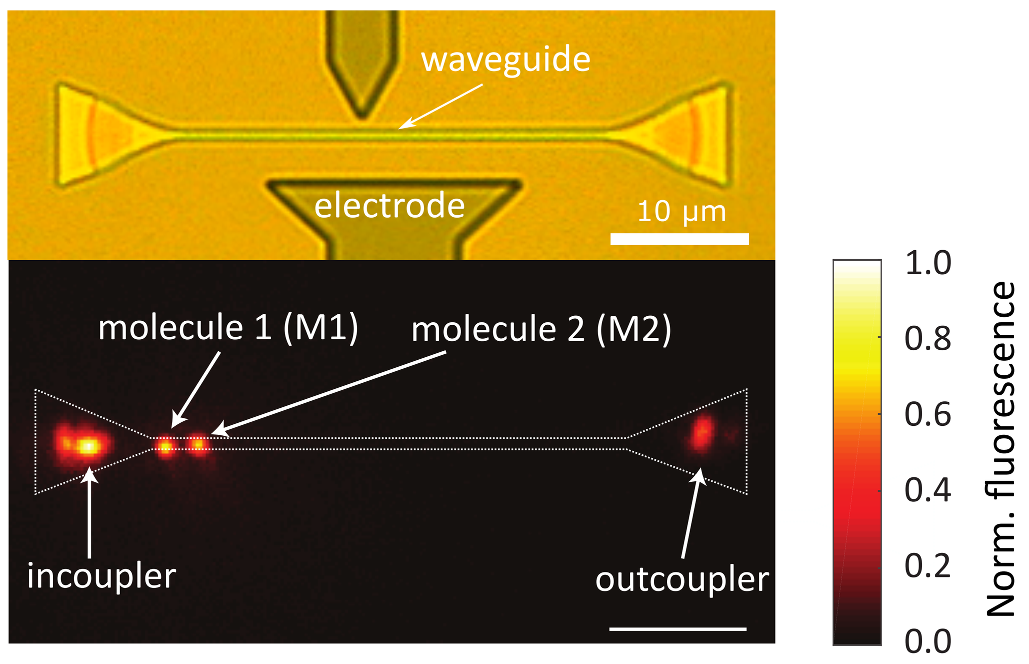


transmission $T = \frac{P_T}{P_I} = (1-\eta\beta)^2$ reflection $R = \frac{P_R}{P_I} = (\eta\beta)^2$

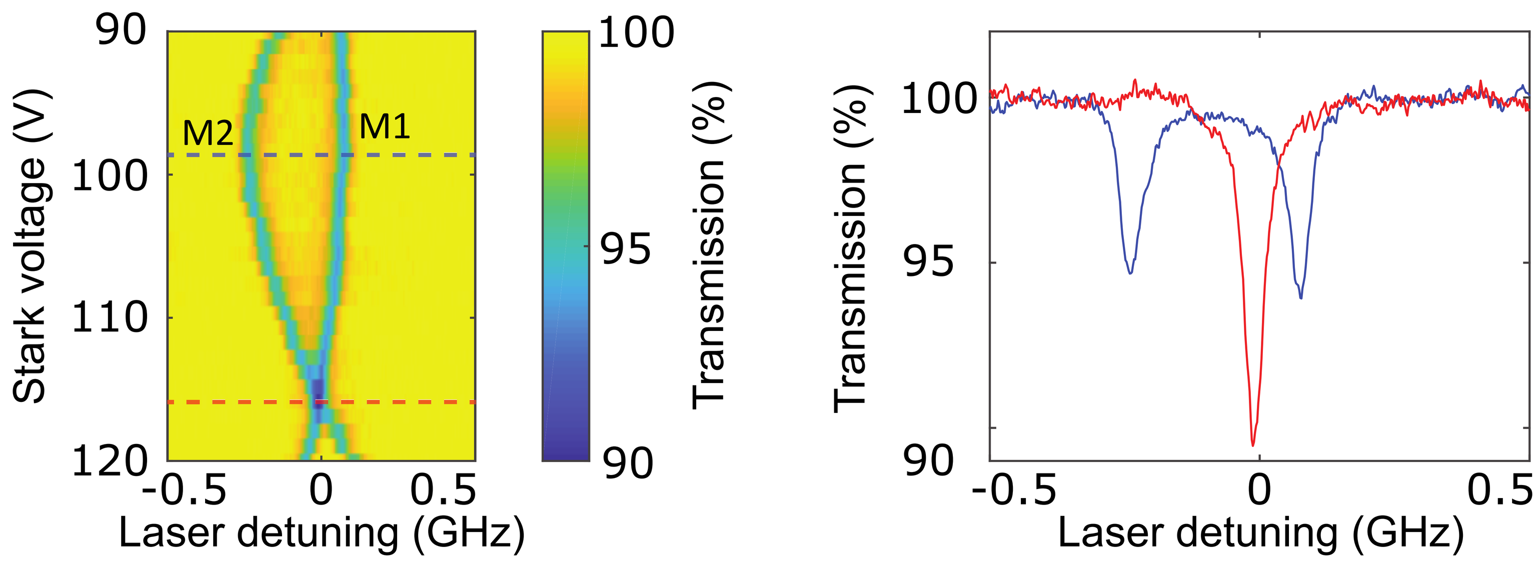


Control of the molecular resonances

- incoporated ITO electrodes to enable DC-Stark shifts

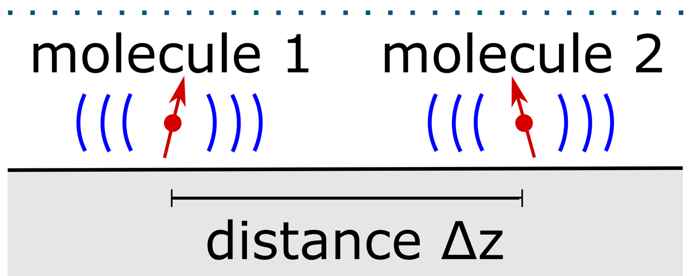


- Stark-shifts of several GHz per 100 V
- matching the resonance frequency of two molecules

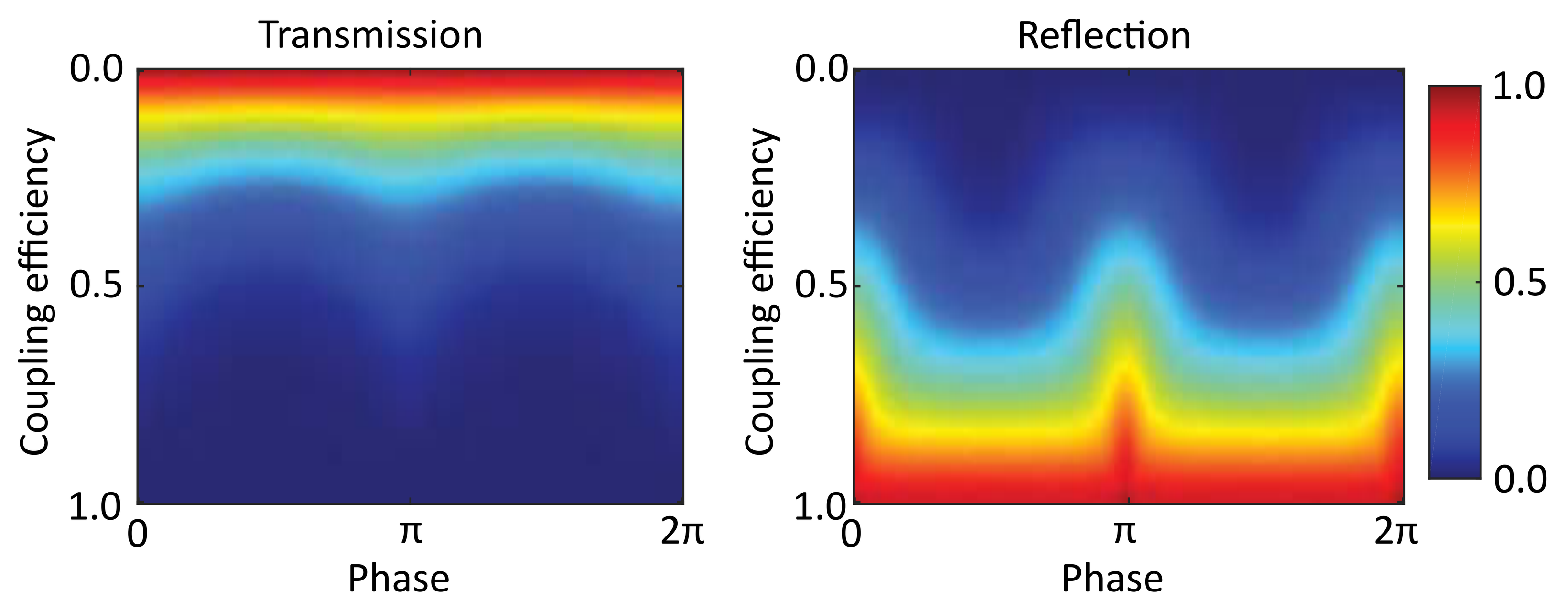


Dipole-Dipole Interaction

- interaction potential depends on the relative phase $\varphi = n_{\mathrm{eff}} \cdot \frac{2\pi}{\lambda} \cdot \Delta z$



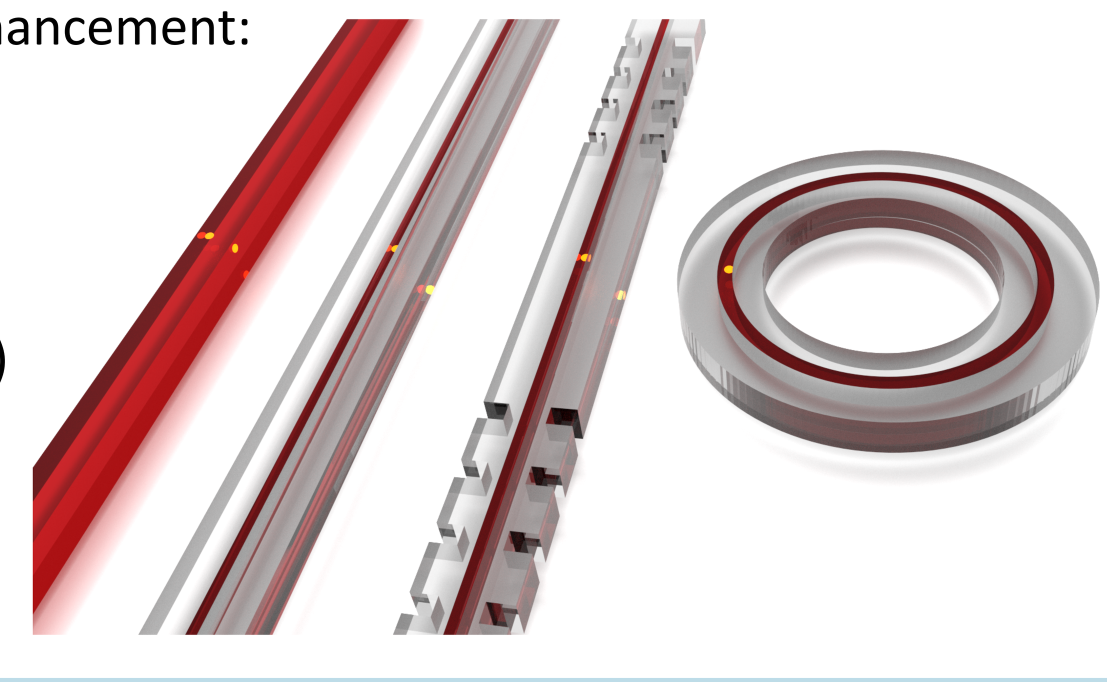
- transmission and reflection for two resonant molecules is sensitive to the effective phase:



- continous transistion from dissipative to dispersive coupling

Future Directions

- exploration of polaritonic behaviour and many-body states
- enhancing β [3]:
  - evanescent field enhancement: (slot waveguides)
  - field enhancement (ring resonators, Fabry-Perot cavities)
- integration into more complex photonic circuits



[1] H. Haakh, S. Faez, V. Sandoghdar, Phys. Rev. A **94**, 053840 (2016).
[2] S. Faez, P. Türschmann, H. Haakh, S. Götzinger, V. Sanodghdar Phys. Rev. Lett. **113**,213601 (2014).
[3] P. Türschmann, N. Rotenberg, J. Renger, I. Harder, O. Lohse, T. Utikal, S. Götzinger, and V. Sandoghdar, Nano Lett., **17**(8), 4941-4945 (2017).
[4] N. Rotenberg, P. Türschmann, H. Haakh, D.-M. Cano, S. Götzinger, and V. Sandoghdar, Optics Express **25**, 5397, (2017).