Nanoantennae on AFM-Tips for enhanced fluorescence detection

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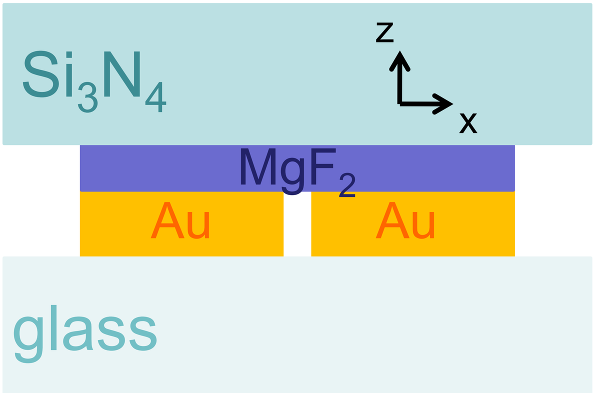
Motivation

To investigate the enhanced light-matter interaction mediated by optical nano antennas, there is a need for reliable quantum emitters (QE). Nanodiamonds (ND) with N-V-centers and single-walled carbon nanotubes (SWCNT) are a good choice, since they are photostable and presumably do not blink.

Simulations

The material that surrounds an optical antenna strongly influences both the resonance length and the radiation direction. The following results are obtained for a wavelength λ = 981 nm, which suites (6,5) SWCNT.

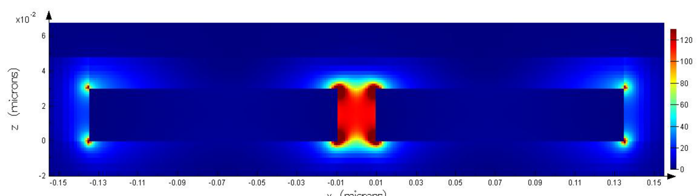
Geometry:



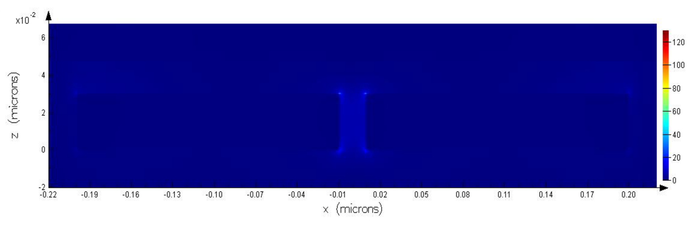
Simulated geometry for a nano antenna on AFM-Tip in contact with glass-slide. MgF_2 between gold and silicon-nitride improves directivity and shifts the field maximum to the glass interface. Sitting on a pedestrial is more realistic and even better for radiating through glass.

Electric fields:

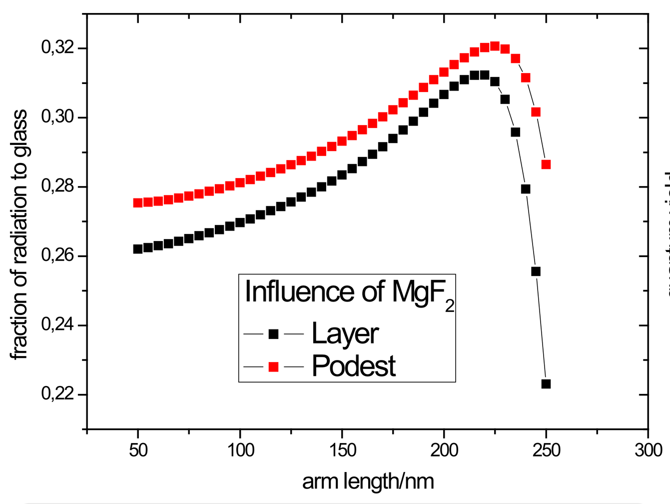
Plane through middle of antenna in x-z-plane. Rods have a 30x30 nm² cross-section, separated by 20 nm.

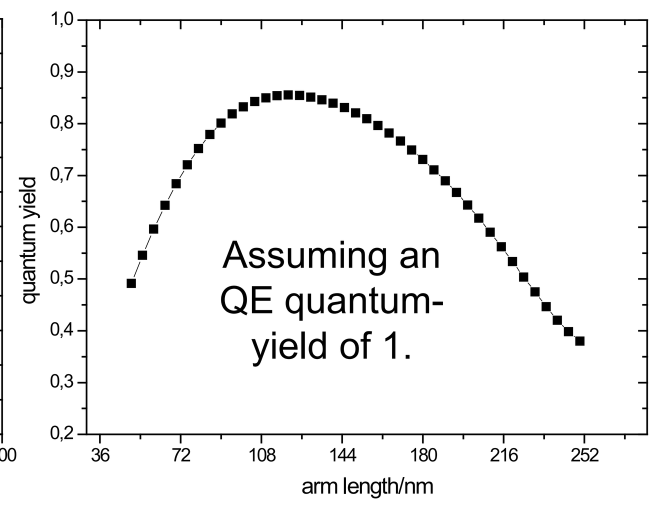


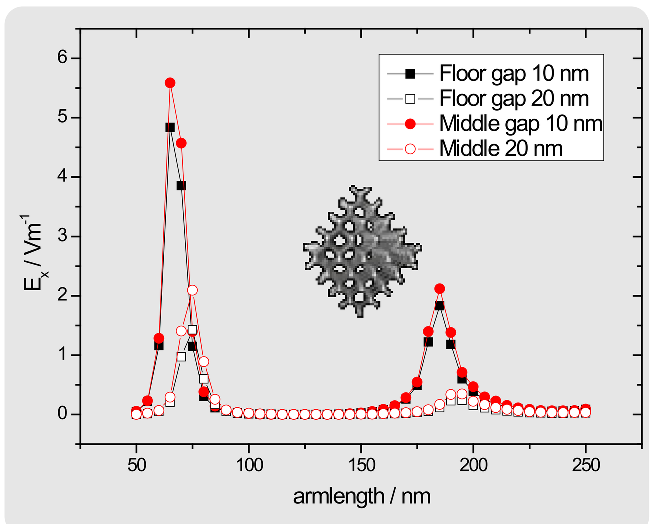
Resonant case with 270 nm total length. Coupled dipole mode.

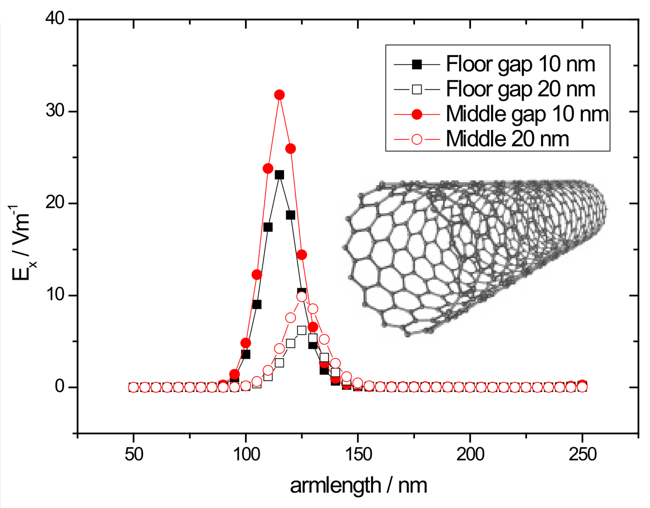


Non-resonant case with 400 nm length. lower fields in the gap.







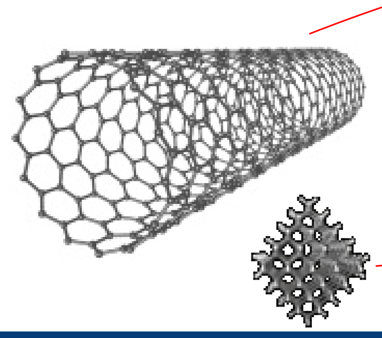


Normalization to a gaussian beam in vacuum. For SWCNT's enhancement and producability are better: first experiments.

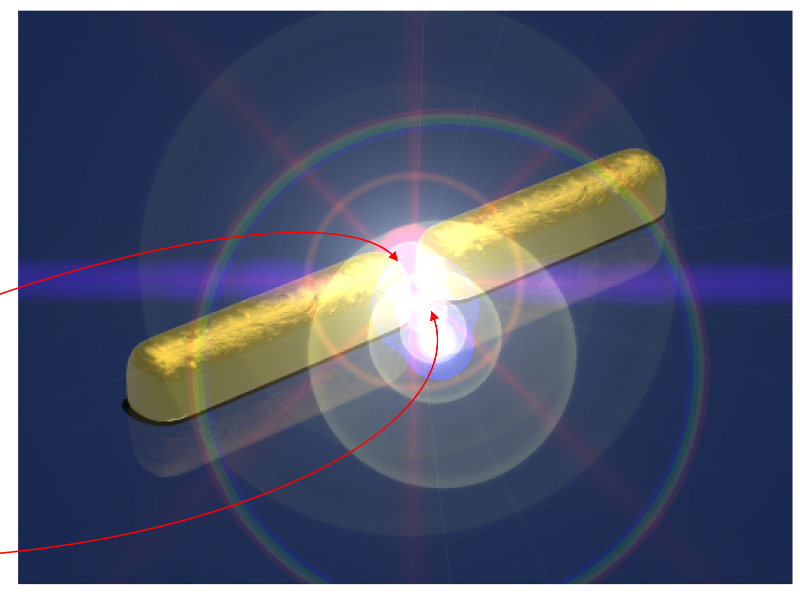
Optical nano antenna

An optical nano antenna, consisting of two small gold nanorods allows to focus incoming farfield-radiation in a highly confined near field in its feedgap, if it is resonant. Emission of quantum emitter with the same wavelength placed in the gap region is thus enhanced, as described by:

$$\frac{\gamma}{\gamma_0} = 1 + \frac{6\pi\varepsilon_0}{|\mathbf{p}|^2}\frac{1}{k^3}\mathrm{Im}(\mathbf{p}^* \cdot \mathbf{E}_s(\mathbf{r}))$$

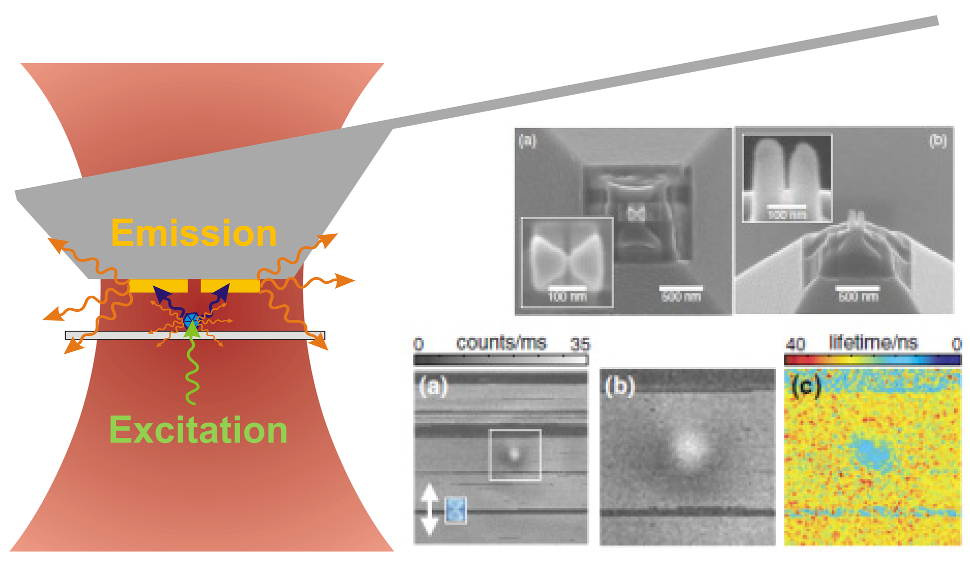


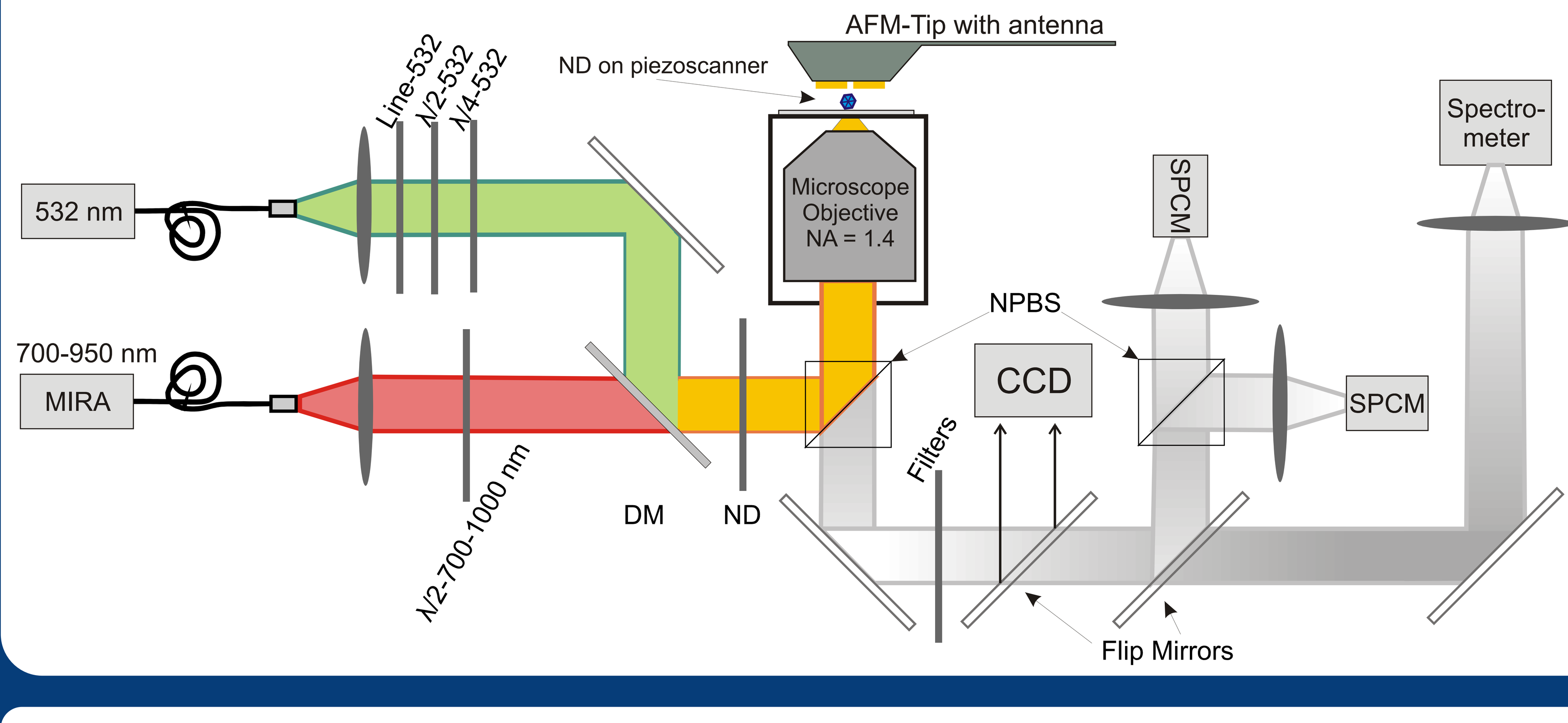
(6,5) SWCNT and ND with N-V-defects as a color center experience higher radiation rates, when placed in near field.



Idea and Realisation

Goal: Enhancement of emission rate, saturation rate, radiative decay of spin-coated or drop-casted ND or SWCNT by approaching the gap of a nano antenna. As Farahani et al. showed with a bowtie-antenna, that this can be achieved with an AFM-Tip [1].
Fluorescence rate can potentially be enhanced by large factors of ~10^3, and also the total quantum yield of the whole system, since the intrinsic non-radiative decay path is in competition with the much more probable energy transfer to the optical nano antenna.

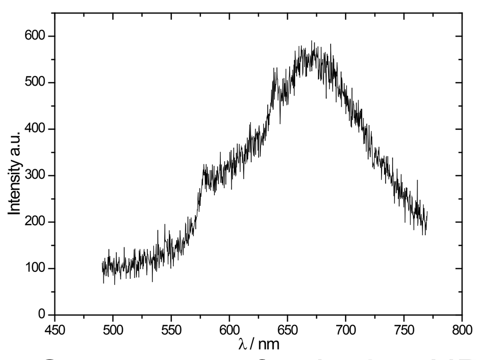




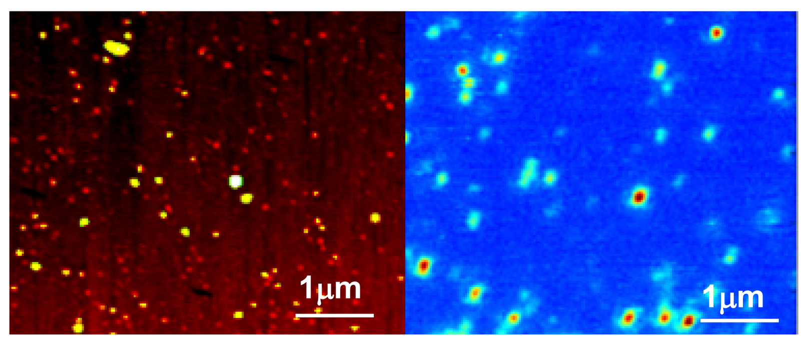
Scheme of setup

DM: Dichroic mirror, ND: neutral density filter, CCD: Camera, NPBS: 50-50 nonpolarising beam-splitter, SPCM: single photon counting module

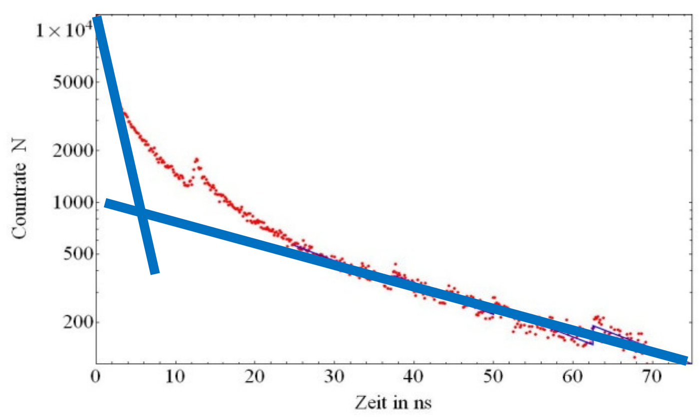
Single-emitter characterization



Spectrum of single ND with two or more defects.

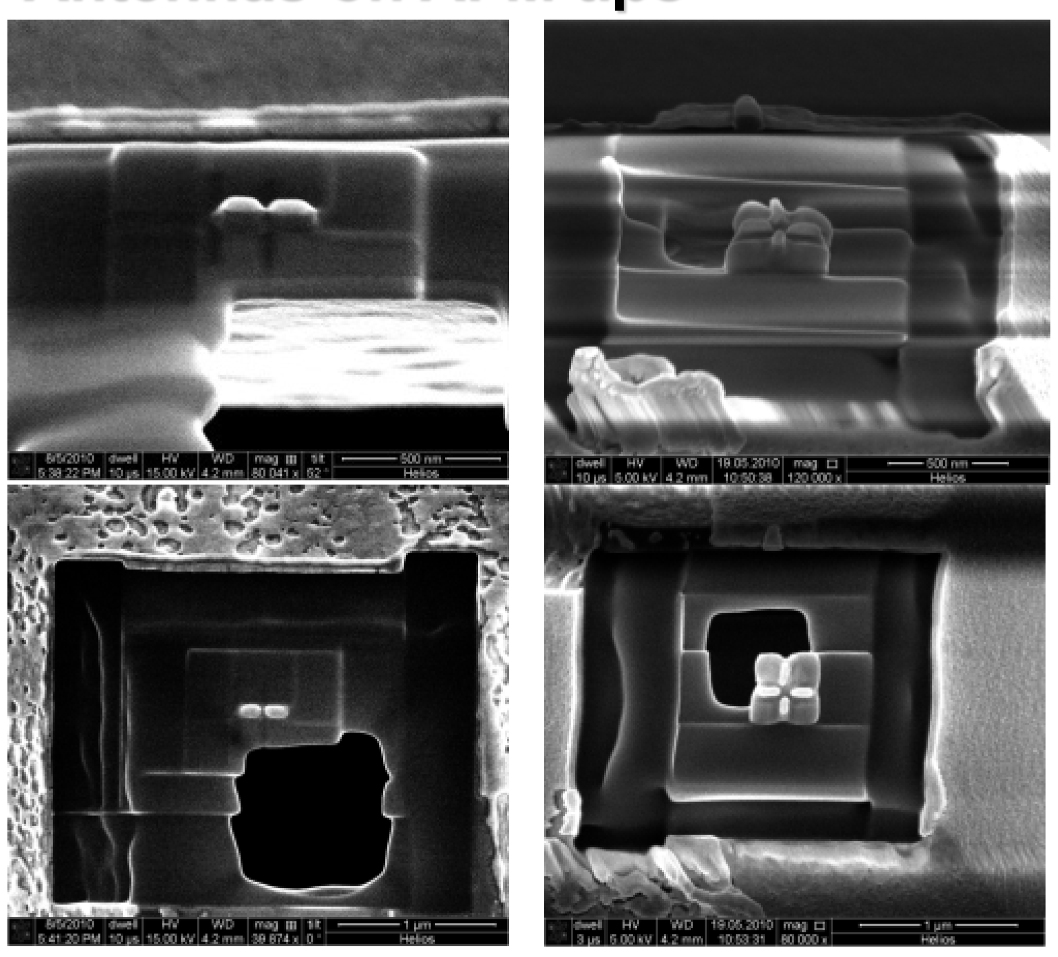


Fluorescing fraction in an area of 5 x 4.5 nm² of dropcasted ND (Krueger-group):
AFM: ~ 160 peaks
Conf: ~ 50 peaks
About 31 % flourescent



Lifetime measurement of NV-Centres shows elongated decay time of ~23 ns compared to bulk lifetime of ~11 ns. Also visible is a very short deacy of ~2 ns: graphene shell?

Antennas on AFM tips



Focused-ion beam milling on flattened tips with 30 nm Au on 20 nm MgF_2. Demanding since focusing the ion beam already removes some gold, space is limited and the remaining gold has a weak adhesion to MgF_2.

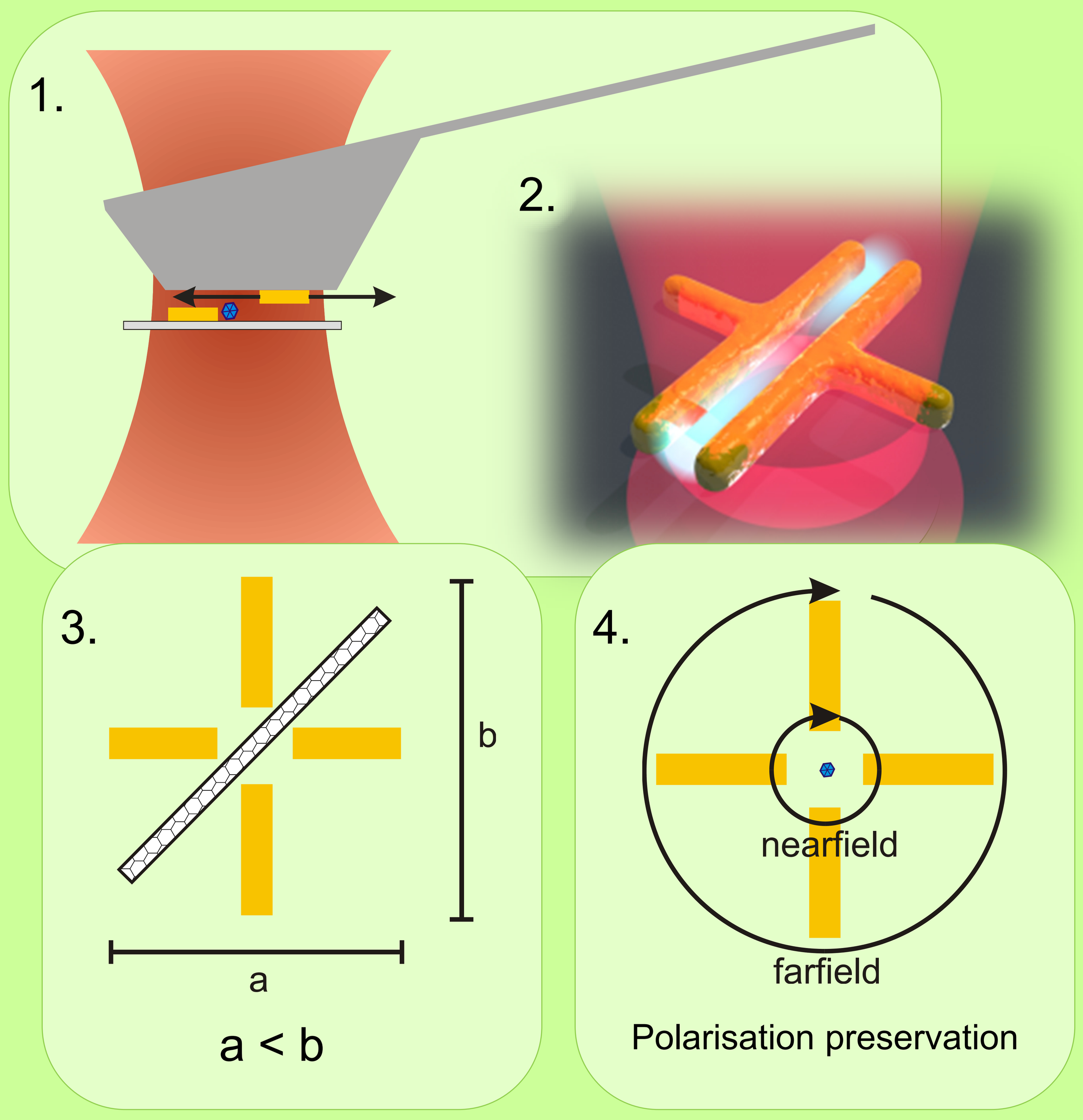
Outlook

Short-term goals:

- White-light-spectroscopy on antennae on tip
- Confocal imaging and characterization of SWNT's (and ND's)
- Optimize translation stage for independent rough positioning of AFM and sample
- Couple antenna with SWCNT
- Test aluminum for N-V-centers

Long-term goals:

1. Understand influence of gap width in experiment
2. Examine possible devices with plasmonic cavities
3. Resonant excitation *AND* emission of CNT's with crossed antennae
4. Influence spin of ND's with crossed antennae and circular polarization [2]



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References:

[1] Farahani et al.: *Single Quantum Dot Coupled to a Scanning Optical Antenna: A Tunable Superemitter;* Phys. Rev. Lett. **95**, 017402 (2005)

[2] Biagioni et al.: *Near-field polarization shaping by a near-resonant plasmonic cross antenna* ; PHYSICAL REVIEW B **80**, 153409 (2009)

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