Plasmonic nanocircuitry with embedded subwavelength waveguides and Yagi-style antennas

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Abstract: High confinement in plasmonic waveguides usually comes along with high loss. We present experiments on a new approach, which allows to tune adiabatically between high confinement and low loss waveguides, connected to optical Yagi-style antennas.

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1. Confinement vs. loss in plasmonic waveguides

Plasmonic waveguides allow for guiding light in structures with a confinement of the electromagnetic field, slightly above [1] to even far below the diffraction limit [2].

In plasmonics, an increase of confinement usually comes along with growing propagation losses due to a higher field overlap with the lossy metal, thus limiting the applicability for optical nano-circuitry applications.

Plasmonic gap [3,4] or slot waveguides [5] have proved to achieve comparably maximum field confinement. However, the minimum loss limit of typical SPP air-gap waveguides, structured into metal layers on a dielectric substrate, is given by the cutoff of their guided modes due to a drop of their effective refractive index below that of the substrate.

2. Embedded plasmonic gap waveguides with adiabatically tunable loss

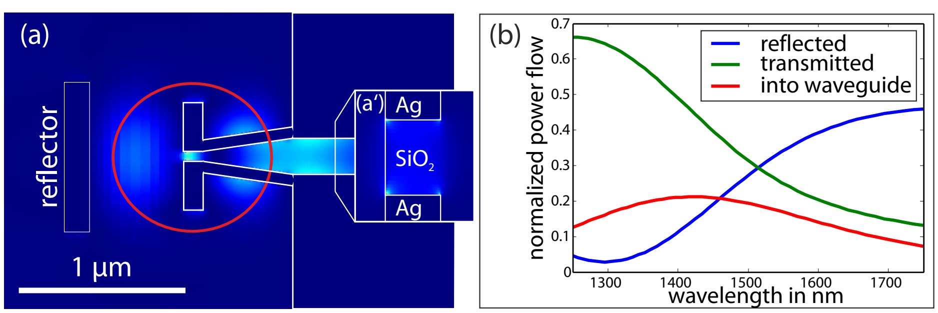

Fig. 1. (a) Optimized optical Yagi-style antenna. Field distribution $|E_y|$ in the substrate plane, obtained from a full 3D FDTD simulation. Simulating the excitation with a Gaussian beam of N.A. 0.9 from air (red circle). (a') Field distribution in a cross section with 300 nm × 300 nm gap size. (b) Reflection, transmission and coupling efficiency of an antenna, which is optimized for $\lambda = 1550$ nm.

Here we present numeric calculations and experimental results on a novel approach to achieve highly subwavelength (down to around 100 nm) integration of guided plasmonic waves, which allow for an adiabatic transition to waveguides with considerably reduced loss and slightly lower confinement.

These waveguides are fabricated by embedding metallic inlays into a silica substrate, or alternatively into a silicon on insulator (SOI) template. Filling the gap of a usual plasmonic gap waveguide with a dielectric, increases the effective

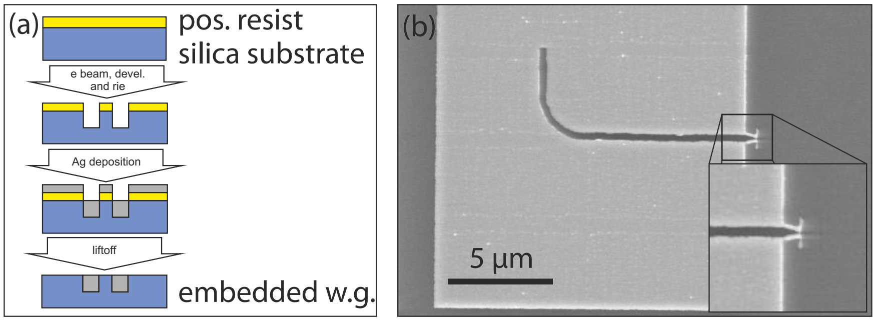

Fig. 2. (a) Fabrication process for embedded SPP waveguides. (b) SEM of a Ag in quartz sample with a optical Yagi-style antenna and a short waveguide for testing the spectral properties.

index of the guided modes. Thus, the cutoff gap width of the guided mode is shifted to far higher values, allowing for SPP waveguides with much lower loss and slightly lower, but still subwavelength, confinement. Propagation lengths of 20 µm with confinement of 300 nm at a wavelength of 1550 nm are observed. These waveguides show low bend losses (below 15 % for $R = 2\,\mu$m) and directional coupling with short coupling length of few microns is feasible. Particularly interesting is the ability to connect low-loss with high-confinement waveguides to a single directional coupler.

3. Connected efficient Yagi-type optical antennas

Coupling into plasmonic gap waveguides with matched optical antennas has proved to be an efficient way to probe SPP circuitry components [3, 4]. Here we combined the embedded SPP waveguides with highly efficient optical antennas, which facilitate the principle of a directional Yagi antenna (fig.1 a) to achieve efficiencies up to 22 % (from air) and 27 % (from dielectric) when coupling a focused beam of light (N.A.=0.9) into the waveguides (fig.1 b).

To increase the coupling efficiency, the waveguide gap is tapered towards the antenna. A Yagi-style optical reflector reduces antenna emission into the sample plane and therefore strongly enhances antenna efficiency.

Antenna design and geometry parameters were found and optimized for optimum coupling of a focused Gaussian beam with NA $= 0.9$ and $\lambda_0 = 1550$ nm using 3D FDTD calculations with a particle swarm optimization (PSO) algorithm and frequency domain FEM calculations [1].

4. Fabrication and measurement scheme

We fabricated the embedded SPP waveguides together with the Yagi style antennas in a single combined e-beam, RIE and liftoff fabrication process (fig. 2 a). The resulting samples (fig. 2 b) offer plasmonic structures, embedded in a silica matrix. At the same time a plane surface across the whole sample allows to scan the electromagnetic near field from all SPP circuitry components with a Near Field Scanning Optical Microscope (NSOM) without being obstructed by topographic features.

Respective measurements are in progress and will be shown at the conference.

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