

Guiding Light on the Nanoscale Stanford University Materials Science and Engineering Department, Nanoscale Electronics and Photonics Group, Prof. Mark Brongersma

Customer Profile

The research of the Nanoscale Electronics and Photonics Group of Prof. Brongersma at Stanford University is focused on the fabrication and characterization of nanometer-sized electronic and optical devices. In this field, Prof. Brongersma is investigating the optical properties of metallic nanostructures. These structures exploit the unique properties of plasmon excitations on metallic surfaces to provide the possibility of confining, transmitting and manipulating light on a scale far smaller than the wavelength of the incident photons.

Initial Situation

For future developments in nanotechnology, it is essential to provide communication channels that allow controlled information and energy transport at the nanometer level. The design of a dense network of electronic interconnects that can link together enormous numbers of nanoscale devices on a chip is not a trivial task. Reductions in the

pitch and cross-section of metallic interconnects gives rise to local heating and an increase in the RC time constant (delay) of interconnected structures. Optical interconnects do not exhibit such problems. Moreover, optical interconnects have a much higher information carrying capacity because of their higher operating frequency. Unfortunately, conventional optical interconnects do not scale down well. The reduction in size of dielectric optical components is fundamentally limited by the diffraction limit of light. Providing a mechanism that allows optical interconnection with individual nano-devices beyond the limits set by diffraction would tremendously expand the information processing capabilities of nanoscale structures. Metal nanostructures often possess exactly the right combination of electronic and optical properties to tackle these issues in order to realize the dream of significantly faster processing speeds. The metals commonly used in electrical interconnection such as

Cu and Al allow the excitation of surface plasmon-polaritons (SPPs). SPPs are electromagnetic waves that propagate along a metal-dielectric interface and are coupled to the free electrons in the metal.

Instrumentation

In order to investigate these surface plasmon-polaritons (SPPs), the group of Prof. Brongersma uses the WITec scanning near-field optical microscope alpha300 S. For experiments on plasmonic waveguides, the Nanoscale Electronics and Photonics Group at Stanford has modified the alpha300 S into a photon scanning tunneling microscope (PSTM). In the PSTM, SPPs can be excited along a metal structure or interconnect by focusing an excitation laser on the structure using a microscope objective. The propagation of the SPPs can be imaged using a microfabricated WITec SNOM-cantilever probe. These probes have a sub-wavelength aperture (about 50 nm diameter) at the apex of a hollow pyramidal tip through which light can be scattered, collected, and then directed toward a photodetector, such as a photomultiplier tube. The detected signal provides a measure of the local light intensity directly underneath the tip, and by scanning the tip over the metal surface, the propagation of SPPs can be imaged. The optical resolution achievable with the alpha300 S is in the range of 50 – 100 nm.

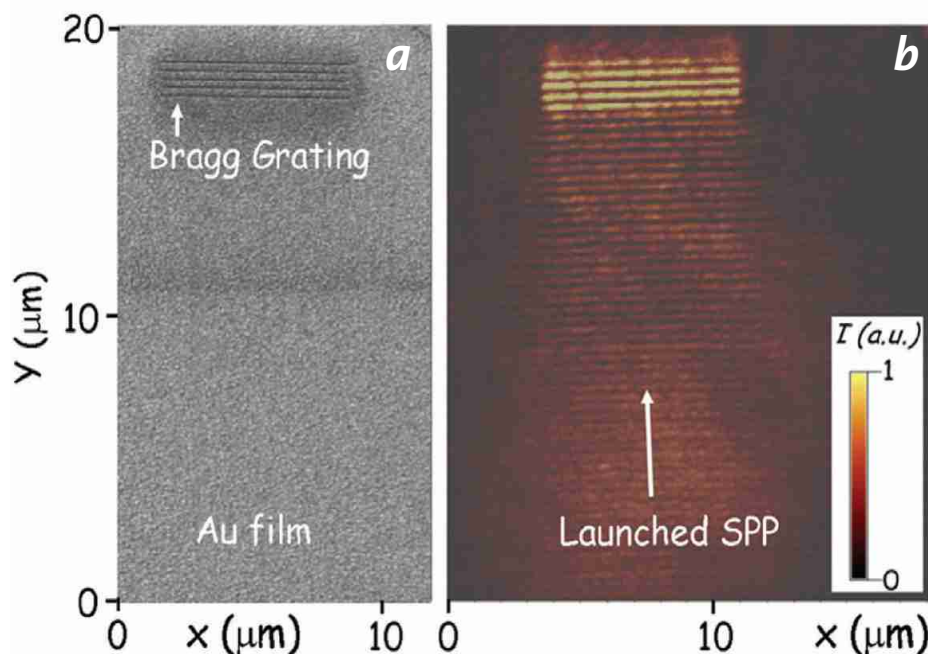


Fig. 1: a) SEM image of a Au film into which a Bragg grating has been fabricated using an FIB. (b) PSTM image of an SPP wave launched along the metal film toward the Bragg grating. The back reflection of the SPP from the Bragg grating results in the observation of a standing wave interference pattern.

Typical Results

1.) The operation of the alpha300 S in PSTM mode can be illustrated by investigating the propagation of SPPs on a patterned Au film (Fig. 1a). Here, a focused ion beam (FIB) was used to define a series of parallel grooves, which serve as a Bragg grating to reflect SPP waves. Fig. 1b shows a PSTM image of an SPP wave excited with a 780 nm wavelength laser and directed toward the Bragg grating. The back reflection of the SPP from the grating results in the standing wave interference pattern observed in the image. From this type of experiment, the wavelength of SPPs can be determined in a straightforward manner and compared to theory.

2.) Electron beam lithography has been used to generate 55 nm thick Au stripes on a SiO₂ glass slide with stripe widths ranging from

50 nm to 5 μm. Au stripes are ideal for fundamental waveguide transport studies as they are easy to fabricate, do not oxidize, and exhibit a qualitatively similar plasmonic response to Cu and Al. Fig. 2a shows an optical micrograph of a typical device consisting of a large Au area from which SPPs can be launched onto metal stripes of varying width. A scanning electron microscopy (SEM) image of a 250 nm wide stripe is shown as an inset. The red arrow shows schematically how light is launched from a focused laser spot into a 1 μm wide stripe. Figs. 2b, 2c, and 2d show PSTM images of SPPs excited at 780 nm and propagating along 3.0 μm, 1.5 μm, and 0.5 μm wide Au stripes, respectively. The 3.0 μm wide stripe can be used to propagate signals over several tens of microns.

Achieved Improvements

With the alpha300 S used in the PSTM mode, it is possible to image SPP propagation directly in plasmonic structures and devices of more complex architecture to determine their behavior. This is quite different from typical characterization procedures for photonic devices in which the device is seen as a black box with input and output ports. In such cases, the device operation is inferred from responses measured at output ports to different stimuli provided at the input ports. The PSTM provides a clear advantage by providing a direct method to observe the inner workings of plasmonic devices, offering a peek inside the box.

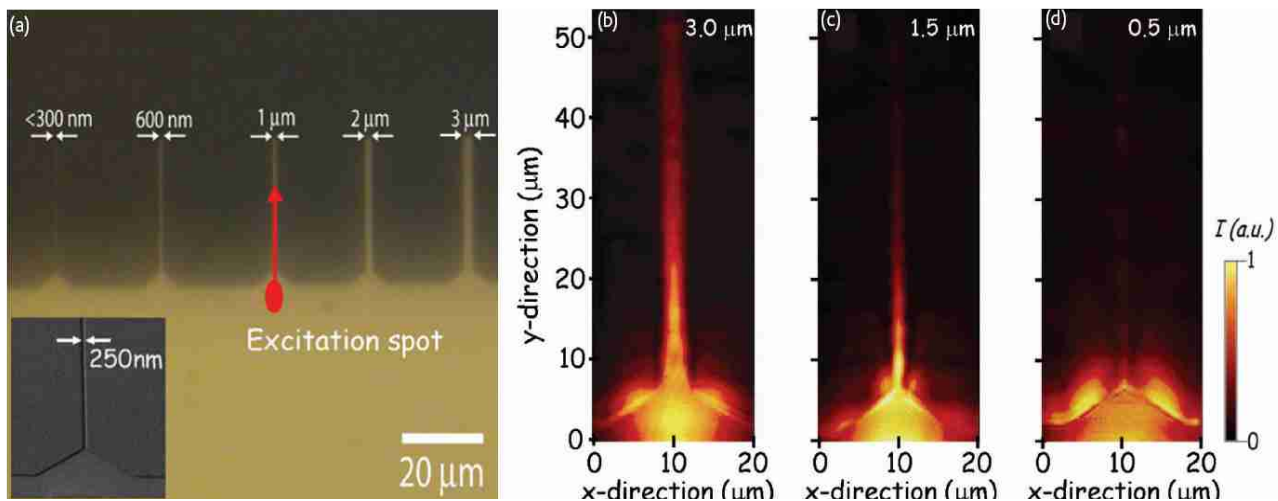


Fig. 2: (a) Optical microscopy image of a SiO₂ substrate with an array of Au stripes attached to a large launchpad generated by electron beam lithography. The red arrow illustrates the launching of an SPP into a 1 μm wide stripe. (b, c, and d) PSTM images of SPPs excited at 780 nm and propagating along 3.0 μm, 1.5 μm, and 0.5 μm wide Au stripes, respectively.



“The valuable information about plasmonic structures provided by the WITec alpha300 S allows us to evaluate the utility of plasmonics for interconnection more thoroughly.”

Prof. Mark Brongersma, Stanford University

Fig. 3: Prof. Mark Brongersma