Plasmonic Antenna for Magneto-Optical Imaging at the Deep Nanoscale.

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Abstract – We report on the modelling and preliminary experimental data on plasmonic antennas that are being designed and constructed for incorporation into a modified atomic force microscope (AFM) head. The antenna structures are fabricated using a silicon templating technique and the AFM head is the key element in a novel time-resolved scanning Kerr microscope (TRSKM), which is targeted to achieve simultaneous ps-time and sub-wavelength spatial-resolution.

An improved understanding of magnetization dynamics at the nanoscale is now required to underpin the development of future generations of hard disk drive and magnetic random access memory devices that are faster, and have increased capacity. A variety of techniques have already been developed to explore magnetism at the nanoscale, and of these various scanning probe and wide field microscopy methods, magneto-optical microscopy is arguably the most versatile.

The time-resolved scanning Kerr microscope (TRSKM) is a table-top instrument with unrivalled temporal bandwidth, that can detect the deflection of the vector magnetization [1] through angles of ~0.1°, with a spatial resolution of up to 300 nm using a high numerical aperture objective lens. However, further improvement of the spatial resolution to below 100 nm is required to study and understand nanomagnetic structures and magnetisation dynamics on the nanoscale. The purpose of this work is to develop a plasmonic antenna tip that can be incorporated in a modified AFM head, which in turn will be integrated within a TRSKM (effectively replacing the objective lens of the current instrument) to facilitate this goal.

The development of a plasmonic antenna represents an extension to three dimensions of planar, single nano-aperture structures in which surface plasmons (SPs) are excited as a means of enhancing and/or controlling the transmission of light through a nano-aperture, notably the bulls-eye grating structure [2] or the prism coupled subwavelength aperture developed in our own lab [3]. There has been intense theoretical and experimental effort devoted in recent years to the development of novel plasmonic antenna with various landmark developments such as the conceptual [4] and experimental [5] development of adiabatic compression and nanofocusing of SPs and the experimental fabrication of innovative tip structures [6], notably and the ‘so-called’ campanile tip [7].

Figure 1 – Kerr rotation and ellipticity for light incident on planar magnetic film (unfeatured lines) with optical data for permalloy used as exemplar case and for same film addressed via pyramidal tip structure with Au bow-tie antenna as illustrated in the inset. The main body of the pyramid is dielectric ($n = 1.5$); Au is 100 nm thick with 100 nm gaps along the edges of the bowtie. Other detail is given in the text.

In all of the above developments strong and often exclusive emphasis is placed on field localisation and field enhancement. Here, in addition to requiring the retrieval of optical information on the nanoscale we must also address the issue of capturing...
and understanding polarisation information. To illustrate this, figure 1 presents modelled data showing the Kerr rotation and ellipticity for a bow-tie plasmonic antenna placed at a 100 nm proximity to a magnetic surface (see inset). Here a plane wave is incident on the back of the antenna and light is collected back through the nano-apertured bow-tie structure. There is notably significant structure and enhancement in this data relative to that for light reflected back from the magnetic film without any intermediate pyramidal antenna. There appears to be good evidence of plasmon enhancement in the Kerr rotation and ellipticity parameters but this preliminary conclusion requires a further analysis to yield a full physical interpretation.

As a first step in working towards a structure and results such as those of figure 1 we have fabricated Au-coated pyramidal tip structures (figure 2, inset). These are based on the well-known anisotropic etching of Si(100) in regions pre-defined by photolithography with subsequent ion milling (to create the grating pattern on one facet only here), Au coating and template stripping. Figure 2 presents ‘transmission’ spectra for the pyramidal structure shown in the inset. In fact, the ‘transmission’ is due to prism-assisted, first order grating coupling between light normally incident on the base of the pyramid and the SP mode at the outer Au-air interface where the SP mode then scatters at the prism apex. While this is not ideal it does not necessarily preclude the retrieval of near field information (without interference from far-field scattering), for example, by collection of light back through an aperture at the apex of the prism. The main feature to note here is the approx. 10:1 ratio in transmission at the p-pol peak. These types of structures, exploiting SP modes on both the outer and internal interfaces are being optimised to improve the polarisation discrimination in order to facilitate magneto-optical measurement.

The authors would like to acknowledge the support of the UK EPSRC.

References


