THE DESIGN AND FABRICATION OF A TIP-ON-APERTURE NEAR-FIELD SCANNING OPTICAL MICROSCOPE PROBE FOR HIGH RESOLUTION PATTERNING

Won Seok Chang[1], Seok-Joo Na[2], Mun Seok Jeong[3]
[1]Nano-Mechanical Systems Research Division, Korea Institute of Machinery and Materials, 171 Jang-dong Yuseong-gu, Daejeon, Korea 305-343
[2]Dept.Mech. Eng., Korea Advanced Institute of Science and Technology
[3]Advanced Photonics Research Institute, Gwangju Institute of Science and Technology
paul@kimm.re.kr

The resolution of commercial optical system is limited to about the wavelength of incident light by the refraction limit. However, a resolution beyond the diffraction limit can be achieved at near-field. Near-field scanning optical microscope (NSOM) is a kind of scanning probe microscope; it can realize a sub-wavelength scale resolution. In NSOM, light is illuminated through an aperture smaller than the wavelength of incident light, and then the small aperture is used as an excitation source. The resolution of the NSOM is determined by the size of the aperture; to achieve a higher resolution, a smaller aperture is required. However, when the diameter of an aperture is smaller than the wavelength of the incident light, the transmission efficiency is proportional to the sixth power of the diameter of the aperture. Thus, a smaller aperture greatly reduces the transmission efficiency. To obtain a sufficiently strong signal from a small aperture, high-intensity light is needed[1]. However, high-intensity light can damage the metal layer of the probe. The typical resolution of aperture NSOM is about 50 nm – 100 nm. In this work, the shape of a NSOM probe was modified using the resolution of numerical analysis based on a finite-difference time-domain (FDTD) algorithm. This probe has a narrow slit or small tip on its aperture. Especially in the near-field area, the electric field intensity distribution is heavily dependent on the polarization of incident light. In the plane of polarization, the electric field intensity of the NSOM aperture probe is strongly enhanced at the edge of the aperture. Simulation results show that this enhancement can be totally or partially removed according to the size of the slit, if the slit carved on the probe is aligned with the polarization direction of the incident light. When a long slit is carved on the probe is aligned with the polarization direction of the incident light. When a long slit is carved on the probe (slit-on-aperture probe), the electric field intensity of the NSOM aperture probe in the plane of polarization shows a Gaussian distribution because the points of enhanced electric field intensity are totally removed. However, when a short slit is carved on the probe, the point of enhanced electric field intensity is removed at one edge of the aperture, and consequently the electric field intensity is enhanced only at the other edge. Moreover, when a tip is put on the probe (tip-on-aperture probe), the electric field intensity is enhanced only near the tip. This means that a higher intensity electric field can be obtained on the surface to be processed in an area smaller than the aperture size.

The tip of a tip-on-aperture (TOA) probe is illuminated through an aperture at the near-field of the probe and electromagnetic interaction between the structure sharp tip at the end of the probe and the surface is used for measurements and materials processing. A novel TOA probe is described, which has a polygonal cross-sectioned tip that can make the strong and local enhancement of electromagnetic field[2,3]. A right triangular pillar was selected as optimal shape of the tip among the several polygonal pillars. The electromagnetic energy distributions at the near-field of the probe and of a typical TOA probe (with circular tip) were calculated numerically, and the results were analyzed. The results show that a TOA probe with a triangle tip confines electromagnetic energy within the smaller area than a typical tip-on-aperture probe, and has 6.7 times the maximum intensity. Moreover, the electric field distributions at the near-field of a TOA probe were calculated numerically to analyze the effects of polarization direction on the characteristics of measurement and processing. A TOA probe is asymmetric for the axis, since it has a probe at metal coated layer on the aperture. The geometrical relationship between this asymmetric shape and polarization direction is the reason for the change of the electromagnetic energy distributions. Numerical analysis shows that a TOA probe can make the best use of the tip for high resolutions when the tip is located on the parallel axis with the polarization direction. After analyzing the trend in the magnitude of the electric field, it was proposed that a localized, enhanced field at the tip apex was caused by the local electric field at the aperture and surface plasmons excited and propagating on the outer surface of the probe.

An NSOM probe is a tinned, metal coated optical fiber with an aperture. To fabricate a TOA NSOM probe, a tip is generated at the end of the probe. FIB processing is applied to the process to make an aperture and a tip, so the aperture and the tip are generated at the same time. With this process, possibilities to fabricate TOA probes with various tips and were shown. And resolution enhancement for optical measurement and patterning was verified using the TOA probe fabricated in this study.

References:

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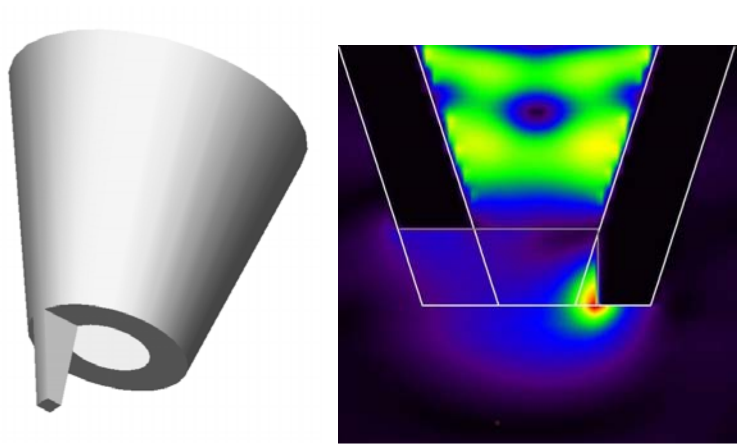
Figures:



(a) **(b)**

Fig.1 (a) Three dimensional modeling and (b) electric field distribution of TOP probe

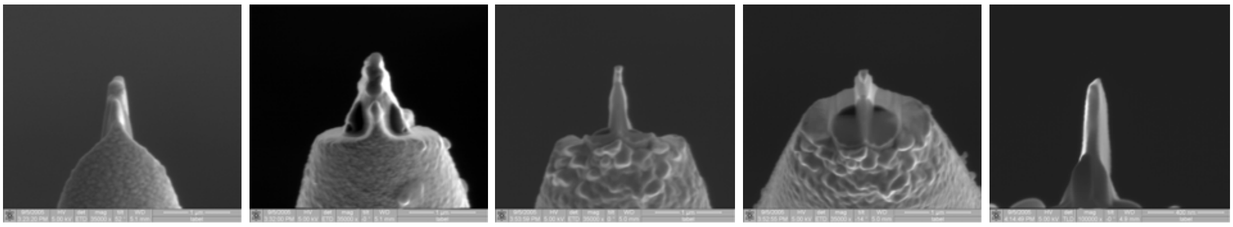


Fig. 2 FIB machined TOA probe