Characterization of less-diffractive nano-scale beam from a ring aperture type plasmonic lens

Hyungduk Ko [1], Seungoh Han [2] and Sungkyu Seo [3,*]

[1] LED Lab., R&D Center, Samsung LED Co. Ltd., Suwon, Gyeonggi 443-743, Republic of Korea
[2] Research Center for Convergence Technology, Hoseo University, Asan, Chungnam 336-795, Republic of Korea
[3] Department of Electronics and Information Engineering, Korea University, Jochiwon, Chungnam 339-700, Republic of Korea

[*]Corresponding author: Sungkyu Seo (Email: sseo@korea.ac.kr, Tel: +82-41-860-1427, Fax: +82-41-866-0401)

Abstract

A perfect lens - the simplest imaging element in optics, which can be fabricated by corrected glass that is a free of aberration, had been thought as the best solution to achieve the smallest focus in a diffraction-limited system. To realize nano-scale focusing, however, recent progresses in micro/nano device fabrication techniques provided alternatives to circumvent polishing the lens more precisely or inventing slightly better dielectric by employing sub-wavelength structures, e.g. periodic or carefully designed apertures[1,2], surface corrugations[3] or gratings coupled with holes[4], which can diffract the incident light or excite and scatter surface plasmon (SP) waves more efficiently. While most of the technologies mentioned above use the SP waves that are strongly bounded to the near-field region of the metal/dielectric interface, i.e. normally within ~λ/2, some research groups reported that nano-scale concentrated beam, formed by plasmonic lens(PL), can be extended to several wavelengths away from the metal surface, namely "mid-field", by careful choosing and designing of the metal[5,6] or metal/dielectric[7] structures.

In this manuscript, for the generation of less-diffractive nano-scale beam in the mid-field region, we characterize several critical parameters, i.e. material, aperture width, metal thickness, and aperture size, of the PL which contains a simple ring aperture as illustrated in Fig. 1. For the numerical analysis, we used TEMPEST, a Maxwell equations solver based on 3D FDTD(Finite-Difference-Time-Domain) simulation, and circularly polarized light of λ_0=405nm incident on the fused silica side of the PL device, and firstly investigated material effect on the nano-scale beaming. As shown in Fig. 2, several highly conductive metals such as Al, Ag, Ti, and Cr which also have been widely utilized in literatures[1-7] were compared by tracking focused beam intensity variation along with propagation axis(Z) of a simple 2μm(R=1μm) ring aperture made of each metal. In all the highly conductive metals investigated, less-diffractive beaming was observed (see Fig. 2(a)) and Al gave the highest intensity in the near-field region, however, as the observation point goes away from the metal surface, 2μm ring aperture in Ag slab showed outstanding beaming performance up to Z=5.4μm which is over 10 fold longer than the incident wavelength. Upon setting the metal of interest with Ag, we analyzed the beaming performance with varied parameters of aperture width(W), metal thickness(T) and aperture radius(R). In Fig. 3, among various conditions, focused beam with the aperture parameter of W150T100 (i.e., 150nm aperture width and 100nm metal thickness) shows relatively uniform beam diameter of 280nm in the mid-field region of 1~4 μm. Also, as described in Fig. 4, a longer radius of the ring aperture delays the less-diffractive uniform nano-scale beaming region slightly to the propagation direction. By focusing incident light to the less-diffractive nano-scale beam, the PL holds a great promise in maskless nanolithography, high-density data storage and optical efficiency improvement of light emitting diode(LED).

References

[1] H. J. Lezec et al., "Beaming light from a sub-wavelength aperture", *Science* **297**, pp. 820-882, 2002.
[2] Z. Liu et al., "Focusing surface plasmons with a plasmonic lens", *Nano Lett.* **5**, pp. 1726-1729, 2005.
[3] F. J. Garcia-Vidal et al, "Focusing light with a single wavelength aperture flanked by surface corrugation", *Appl. Phys. Lett.* **83**, pp. 4500-4502, 2003.
[4] W. L. Barnes et al, "Surface plasmin subwavelength optics", *Nature* **424**, pp. 824-830, 2003.
[5] S. Seo et al., "Subwavelength proximity nanolithography using a plasmonic lens", *J. Vac. Sci. Technol. B* **25**, pp. 2271-2276, 2007.
[6] H. Kim et al., "Finite-size nondiffracting beam from a subwavelength metallic hole with concentric dielectric gratings", *Appl. Optics* **48**, G68-72, 2009.
[7] H. Ko et al., "Light transmission through a metallic/dielectric nano-optic lens", *J. Vac. Sci. Technol. B* **26**, pp. 2188-2191, 2008.

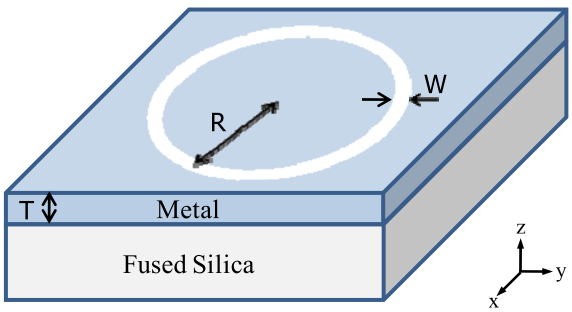

Fig. 1 Schematic diagram of plasmonic lens with a ring aperture

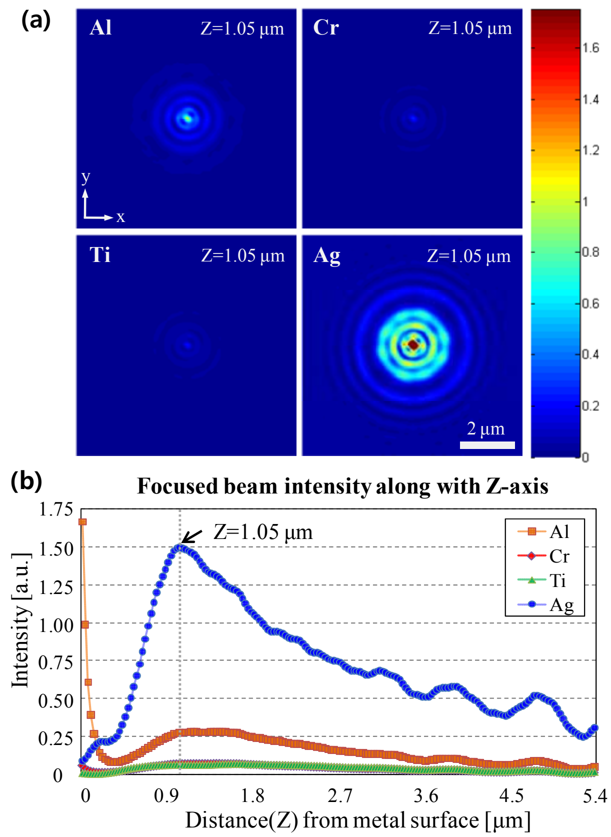

Fig. 2 Focused beam intensities for various metals (i.e. Al, Cr, Ti, and Ag) (a) Intensity distribution in XY-plane at Z=1.05µm (b) Intensity variation along with propagation axis (Z-axis)

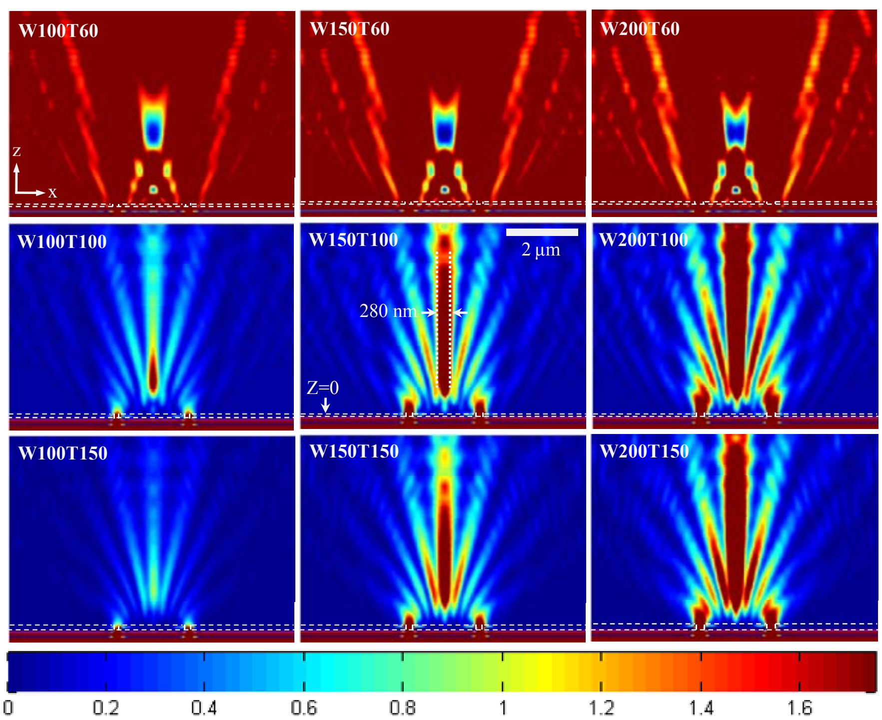

Fig. 3 Formation of less-diffractive nano-scale beam varying with aperture width (W) and metal thickness (T) in silver (Ag) slab

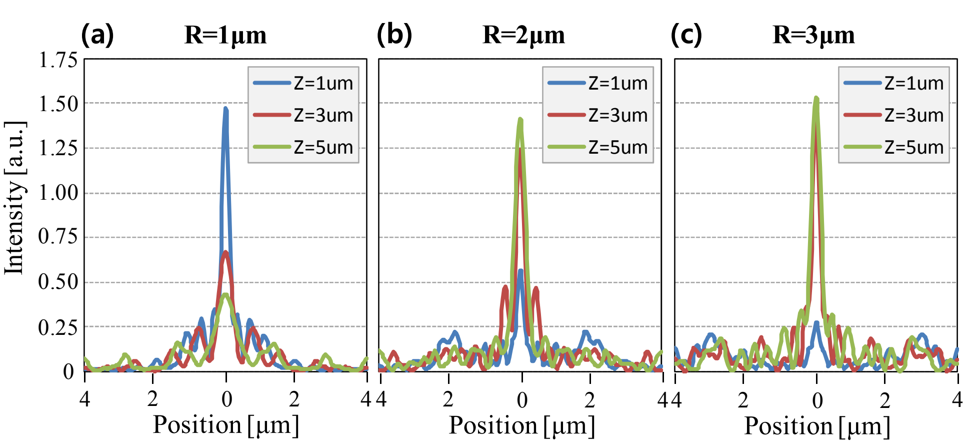

Fig. 4 Propagating beam profiles at Z=1, 3, 5µm with various aperture radii (R), (a) R=1µm, (b) R=2µm, and (c) R=3µm, of Ag plasmonic lens