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Polarization Effect on Silver Nanolines Fabricated by Multiphoton-induced Reduction

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[Introduction] Multiphoton absorption process using femtosecond laser pulses has became a powerful and widely used tool for fabricating micro-/nanoscale structures, because of its simplicity and high resolution. In the case of the repetition rate of MHz order, free electrons generate low density plasma in the focal region inducing photochemical effects [1]. Accumulation over many pulses leads the reduction of metal ions into the neutral metal atoms resulting in the formation of metal nanoparticles, which were eventually aggregated to construct a small structure in the region limited by the focal volume. Using a linearly polarized beam, the lateral width of the fabricated structure is less than 1 μm [2]. To the best of our knowledge, the use of other polarization state of a light beam has not been investigated so far with respect to the fabrication of metallic nanolines through the multi-photon induced reduction.
[Experiment] A metal-ion aqueous solution, which consisted of diammine silver ions (0.05 M) and n-decanoylsarcosine sodium (NDSS, 0.099 M), was placed between a slide glass and a coverslip. This sample system was irradiated by a mode-locked femtosecond Ti:sapphire laser operating at 780 nm with a repetition rate of 100 MHz and the pulse energy up to 2 nJ with 100 fs pulse duration. The beam was introduced into a microscope and tightly focused into the ion solution through the coverslip by an oil-immersion objective lens (100×, NA = 1.45). The input beam size was adjusted using a beam expander to fulfill the back aperture of the objective lens. Line structure composed of silver nanoparticles is then expected to be created on the coverslip after scanning the focused beam in one dimension using a computer- controlled stepping motor integrated to the microscope stage. Linear, circular and cylindrical (radial and azimuthal) polarization states were used. Transformation of a linearly polarized Gaussian beam to a circularly and a cylindrically polarized beam was performed using a λ/4-plate and a duodecimally segmented half wave plate, respectively. The incident power was controlled by a graduated neutral density filter and measured at the entrance of the microscope.
[Results] Figure 1 shows the SEM images of the fabricated silver nanolines by direct writing with femtosecond laser pulse with different polarization states at the same laser power and scanning speed. As expected, lines are created on the path where the focused beam is scanned over the surface. Even though the same scanning speed and laser power, the structures of the lines are significantly different for different polarization states applied. With linear and circularly polarization (Fig. 1(a) and (b)), the nanolines are constructed from nanoparticles (20 - 50 nm) embedded into NDSS surfactant. The embedded particles can be distinguished easily because of its high contrast. Using cylindrical polarization beams, chunks of particles (> 50 nm) are created and gathered to form a line (Fig. 1(c) and (d)). No difference in the contrasts was observed here. Although the reason is unclear, systematic investigation is still on-going and will be presented in details in the conference.

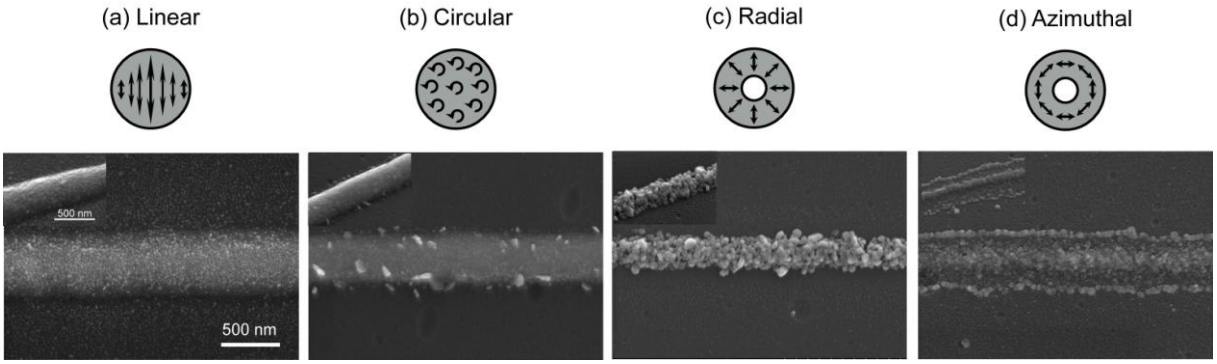

Figure 1. Scanning electron microscope images of silver nanolines fabricated at the laser power of 0.3 mW and the scanning speed of 2 μm/s with different polarization states, (a) linear, (b) circular, (c) radial and (d) azimuthal polarizations. Concentration of silver ions and NDSS are 0.05 M and 0.099 M, respectively. Inset: The corresponding images tilted at 45°.

[References]
[1] A.Vogel, J. Noack, G. Hüttman and G Paltauf, *Applied Physics B: Laser and Optics* **81**, 1051 – 1047 (2005).
[2] Y-Y. Chau, N. Takeyasu, T. Tanaka, X-. M. Duan, and S. Kawata, *Small* **5**, 1144 – 1148 (2009).