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Submicron Processing Using Laser-Induced Photonic Nanojet

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***Abstract*— In this paper, we propose a novel laser-induced photonic nanojet for micro/nanofabrication. The full width at half maximum of the nanojet is smaller than the diffraction limit, thus allowing for the fabrication of structures at the submicron scale. We first developed the experimental nanojet system, which consists of a laser source, an objective lens, a charge-coupled device camera, and a mobile platform capable of three-dimensional movement. Further, the experimental conditions were optimized by simulating the nanojet. The results showed that submicron features could be created successfully on gold electrodes. Thus far, it has been possible to form features as narrow as approximately 300 nm.**

Background

Micro/nanoscale structures and devices are being used widely in many important fields, such as superhigh-resolution imaging and the microchip industry. The most widely used microfabrication technology is lithography, which requires a complex system and a high-precision mask. Therefore, several other microfabrication methods are being explored as alternatives. Laser processing has received a lot of attention as a microfabrication method for the self-assembly of structures as well as for the micro/nanomachining of materials. However, owing to the diffraction limit, it is hard to realize nanoscale fabrication directly using a laser. The photonic nanojet is increasingly being used for nanoscale fabrication since it was first reported by Chen et al.[1] in 2004, because the full width at half maximum (FWHM) of the photonic nanojet can be as small as one-third of the wavelength of the incident light, which is smaller than the diffraction limit. Wu et al. used it to fabricate uniform arrays of nanoholes and nanopillars [2]. Further, McLeod et al. used it for subwavelength direct-write nanopatterning [3], while Chang et al. used it for the high-throughput nanofabrication of infrared and chiral metamaterials[4]. Further, Kallepalli et al. used it for the long-range nanostructuring of Si surfaces [5]. Li et al. used it to fabricate a nanomotor through nanoscale patterning[6], while Yang et al. used it to fabricate nonperiodic metasurfaces[7]. However, despite the many developments in this field, it remains difficult to control the location of the microsphere, which means that it is not easy to fabricate structures at the desired location. Here, we propose a method that allows for the fabrication of features at the expected location.

CURRENT RESULTS

The experimental system is shown in Figure 1. The laser-induced photonic nanojet processing system consists of four parts: an incident laser source and light path for shrinking laser, a light path for imaging, a mobile platform for controlling the specimen being processed, and a mobile platform for clamping the microsphere. The wavelength of the laser is 532 nm and its power ranges from 0 to 300 mW. After being emitted by the laser system, the laser passes through a pair of convex lenses and then a concave lens, which shrinks the incident beam. Next, a beam splitter is used to change the incident angle, so that the specimen is irradiated from the top, and a 50× objective lens is used for imaging. The laser spot is approximately 10 μm in diameter and irradiates a microsphere through the light path. This silica microsphere, which is also 10 μm in diameter, is made to adhere to a tungsten-tipped probe by a UV-curable adhesive. The mobile platform is used to fix the probe as well as control the location of the microsphere at the focal point of the objective lens. The specimen processed was a gold electrode with a thickness of 50 nm; it was fixed to another mobile platform, and the distance between the microsphere and the gold electrode was primarily controlled by this platform.

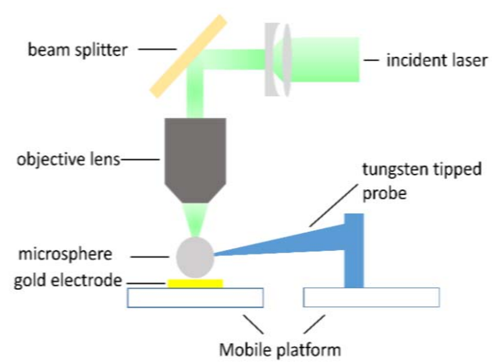

Figure. 1. Schematic of entire experimental photonic nanojet-based laser-processing system.

The simulation results are shown in Figure 2. It can be seen from Figure 2(a) that the diameter of the silica microsphere is 10 μm. The peak photonic nanojet appears 1.19 μm away from the microsphere, as shown in Figure 2(b). Figure 2(c) shows the distribution of the light intensity on the material surface. Further, the simulation results indicate that the FWHM is approximately 1.3 μm. The maximum intensity is seven times greater than that of the incident light. Figure 2(d)

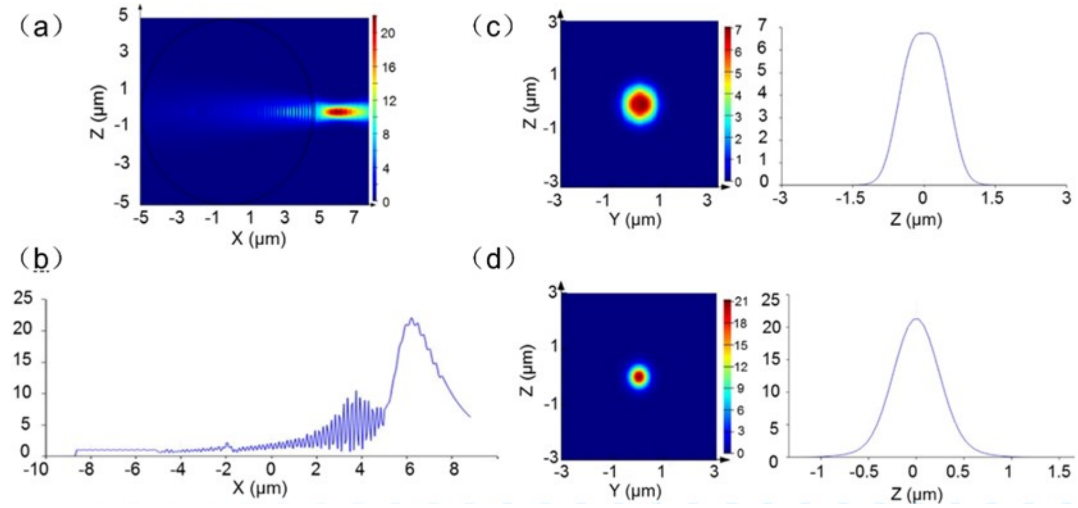

Figure 2. (a) Simulation results for silica microsphere 10 μm in diameter. (b) Intensity distribution along x-axis of (a). (c) Simulation results showing intensity on material surface. (d) Simulation results for plane of photonic nanojet at peak intensity.

shows the distribution of the light intensity on the peak photonics nanojet plane. The simulation results suggest that the FWHM in this case is approximately 560 nm and that the maximum intensity is 22 times higher than that of the incident light. The simulation results also indicate that the features fabricated at the peak photonics nanojet intensity were more precise than those fabricated by the microsphere surface, indicating that the microsphere was in contact with the specimen.

Hence, during the fabrication process, the mobile platform controlled the distance between the microsphere and the specimen to approximately 1 μm, thus allowing small features to be formed. Scanning electron microscopy (SEM) images of the processed gold electrode are shown in Figure 3.

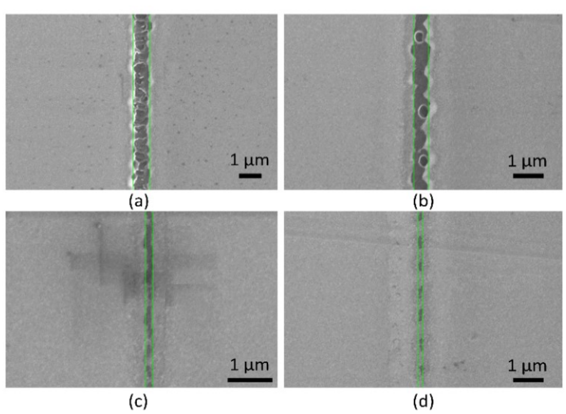

Figure 3. SEM images of specimens processed at laser power of 120 mW and platform moving rates of (a) 5 μm/s, (b) 10 μm/s, (c) 15 μm/s, and (d) 20 μm/s. Scale bars represent 1 μm.

It can be seen that the 10-μm silica microsphere is fixed at the point of focus of the objective lens. The mobile platform for the specimen controls the rate at which the gold electrode substrate moves. The applied laser power is 120 mW. The features produced in the gold electrode are lines, whose width decreases as the moving rate is increased. The narrowest continuous line is approximately 300 nm in width. Thus, it can be seen clearly that even sub-diffraction-limit features can be fabricated using the system as long as the laser power and platform moving rate are chosen appropriately.

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