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Opto-Thermomechanical Nanoprinting under ambient conditions

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Abstract: An opto-thermomechanical (OTM) nanoprinting method is demonstrated to not only additively print nanostructures with sub-100 nm accuracy but also to correct printing errors for nanorepairing under ambient conditions..

Introduction

Additive manufacturing, known as the industrial version of 3-D printing, has already been used at the macroscales by engineers and designers for the rapid prototyping and low-volume production. Unfortunately, such rapid prototyping techniques are yet to be developed for the manufacturing at the nanoscales [1–4]. In this paper, I introduced a new method for laser additive manufacturing at the nanoscales. A laser induced nanoparticle desorption process that is used for the manufacturing is studied [3].

Results

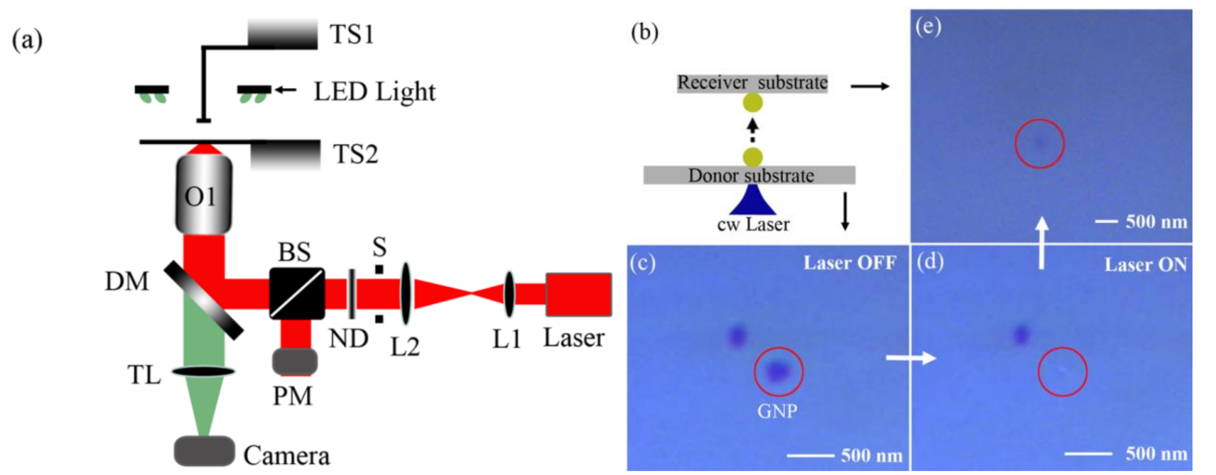

Fig. 1. (a) Layout of the experimental setup. L: lens; TL: tube lens; DM: dichroic mirror; BS: beam splitter; O1: objective lens; PM: power meter; TS: translation stage; ND: variable neutral density filter; S: shutter. (b) Schematic of the release-and-place process. (c) Optical image of GNPs on a donor substrate when the laser is off. (d) Targeted GNP released from the donor substrate when the laser is on. (e) Released GNP on the receiver substrate. Reprinted with permission from ref. [3] Copyright (2018) American Chemical Society.

Fig. 1a schematically shows the experimental setup of the laser-induced nanoparticle desorption approach, which is based on the heating of gold nanoparticles (GNPs) and rapid thermal expansion of a soft substrate. A continuous-wave (CW) laser with a wavelength of 1064 nm serves as the heating laser. The laser beam is first expanded with two lenses and then reflected by a dichroic mirror. Finally, it is focused on the sample with an oil immersion objective lens. A shutter is used to switch the laser on and off. A plastic coverslip is placed on a translation stage for precise position control. Colloidal GNPs with a diameter of 200 nm from BBI solutions are diluted and then dropcast on the plastic substrate. The GNP solution is then left naturally dried on the substrate.

A second substrate is mounted on another translation stage and suspended on top of the plastic substrate. A light-emitting diode light source is used for illumination, and the GNPs on the plastic substrate are imaged on a camera. Because GNPs will be released from this substrate, we call them donor substrate. Fig. 1c shows the optical image of a GNP on the donor substrate when the laser is off. The red circle indicates the area to be illuminated with the heating laser. Once the heating laser is switched on, the GNP is immediately released from the donor substrate. Fig. 1d shows the same optical image after the laser is turned on. The GNP in the red circle desorbs from the donor substrate and transferred to another substrate placed on top of it. Because GNPs are transferred to the top substrate, we call them receiver substrate. Fig. 1e shows the optical image of the receiver substrate with a GNP that is transferred onto. The black dot in the red circle shows the GNP that is placed on the receiver substrate.

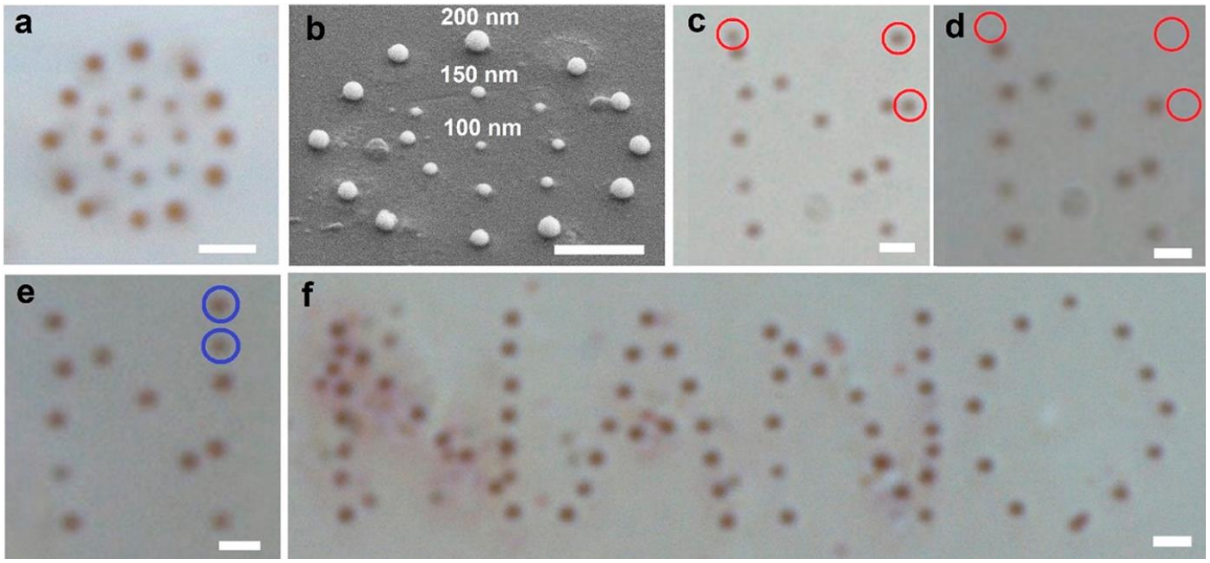

Fig. 2. (a) Optical image of a circular pattern that is formed by selectively printing of three different sizes of GNPs (100, 150, and 200 nm) on a glass substrate. (b) SEM image of the corresponding structure. (c) A letter “N” consisting of 200 nm GNPs is printed on an ITO-coated glass substrate using preheating. The gap between the donor and the receiver substrate was ~1.5 µm. The GNPs inside the three red circles are selected to be removed. (d) Three GNPs are removed from the substrate. (e) Two GNPs (in the blue circles) are added to the letter “N”. (f) Optical image of the word “NANO” consisting of 200 nm GNPs that is formed by applying OTM nanoprinting and nanorepairing process. Scale bars represent 1 µm. Reprinted with permission from ref. [5] Copyright (2020) American Chemical Society.

GNPs can be additively released from the donor substrate and transferred to the receiver substrate for additive nanomanufacturing [5]. The images in Fig. 2a and 2b shows optical and SEM image of a circular structure that is printed on a glass substrate by printing one 100 nm GNP at the center, eight 150 nm GNPs in the first ring, and twelve 200 nm GNPs in the second ring. The OTM technology can also be used to correct printing errors for nanorepairing as shown in Fig. 2ce. The letter “N” is first printed by additive printing of fourteen 200 nm GNPs on an ITO-coated glass substrate with preheating (Figure 2c). To repair the pattern “N”, three GNPs (marked in the red circles) are selectively removed from the letter (Figure 2d). Then two new GNPs (marked in the blue circles) are added to the letter “N” to repair the structure as shown in Figure 2e. Both the nanoprinting and the nanorepairing can be conducted on the same platform under ambient conditions. Figure 2f shows the optical image of the word “NANO” consisting of 200 nm GNPs that are printed and corrected by using the OTM technology.

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