# RAPID FABRICATION OF PERIODIC METALLIC NANOSTRUCTURES USING POLYMER MOLD GUIDED NEAR FIELD PHOTOTHERMAL ANNEALING

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## ABSTRACT

We report on a rapid near field photothermal annealing (NPTA) approach for fabricating metallic nanostructures guided by flexible and transparent polymer molds. Nanosecond laser pulses, after passing through a PDMS phase-shifting mask, spatially redistribute its optical energy at the interface between a PDMS mold and a gold thin film in contact, which selectively melt gold in energy-enhanced areas. Molten gold migrates to cold areas and forms nanostructures. Using NPTA, We have demonstrated rapid fabrication of gold nanowires and nanospheres across a 1 $mm^2$ area.

## INTRODUCTION

Nanostructures have numerous applications in photonics, cell surgery, data storage, and biosensors. Multi-beam Interference Lithography (MIL) has been shown as an effective method for low cost and rapid fabrication of two- and three-dimensional nanostructures[1, 2]. By coupling with nanosecond laser pulses, MIL based photothermal annealing techniques are capable of direct laser printing of periodic metallic nanostructures from thin metal films coated on various types of substrates including glass, silicon, and polymer. [3]. However, MIL is limited to fabricating periodic structures with simple shapes.

Here, we propose, for the first time, a rapid fabrication process capable for fabricating both periodic and non-periodic metal nanostructures with near field photothermal annealing (NPTA) guided by PDMS phase-shifting masks as shown in Fig. 1. A laser pulse with uniform spatial light intensity distribution, after passing the PDMS phase-shifting mask, redistribute its energy distribution and form a non-uniform light intensity profiles at the PDMS and gold interface. The areas with stronger light intensity correspond to regions absorbing more electromagnetic energy in the metal layer due to surface plasmon oscillation. The absorbed electromagnetic energy quickly converts into lattice vibration and heats up the metal film. The laser pulses shaped by the PDMS phase-shifting mask selectively heat up and melt thin film gold in areas with high light intensity. Due to instability of a molten gold thin film on a glass substrate, the molten film migrates to the cold area. The shape evolution of the molten film is controlled by surface tension of the molten gold and the pulse energy, wavelength, duration, and number of pulses illuminated. Since the formation of these gold nanostructures take one to few laser pulses, it has the potential for rapid, large-scale nanofabrication by scanning laser pulses across a large area. Furthermore, since the local shape of a PDMS mold determines the near field light pattern, NPTA has the potential for fabricating any arbitrary 2D shape of metal nanostructures by properly designing the PDMS phase-shifting mask.

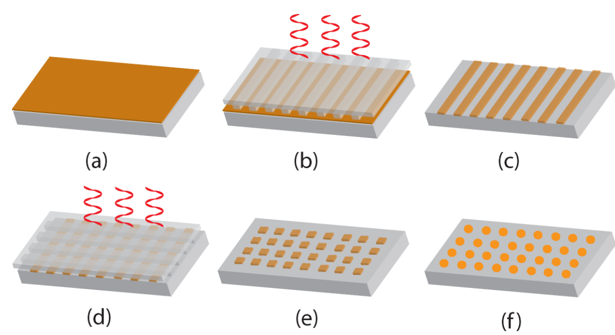


*Fig.1 Schematic of NPTA processes. (a) A thin gold film is coated on a glass slide; (b) A 1-D grating PDMS mold is placed on top of a gold thin film followed by laser pulse illumination; (c) Gold nanowires form after exposure; (d) Rotate the PDMS mold and repeat process (b); (e) Isolated gold squares form; (f) Gold squares bead up and form nanospheres after flood laser exposure*

## SIMULATION and EXPERIMENT

The light intensity distribution near the PDMS mold and gold thin film is simulated using COMSOL Multiphysics and shown in Figure 2. The incident light is TE wave with a wavelength of 532 nm. Fig. 2(a) shows the grating pattern on the PDMS mold with a periodicity of 5/3 μm and positioned in contact with a 10 nm gold film on a glass substrate. Fig 2(b) shows the light intensity distribution near the grating structure and the maximum light near the tips of the triangular protrusion. The intensity distribution on the metal surface is plotted in Fig 2(c). By adjusting the pulse energy, gold thin film near the strong light intensity regions can be selectively melted and migrates to the cold areas.

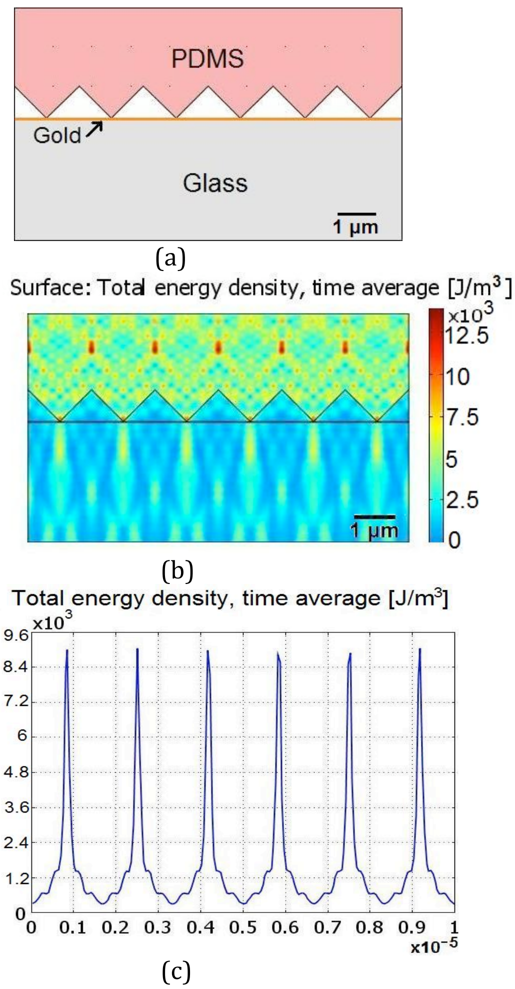


*Fig. 2 (a) Schematic of a phase-shifting PDMS mold and a Au thin film coated substrate used in simulation; (b) Diagram of light intensity distribution; (c) Energy density distribution on the gold surface.*

In the experiment, a Q-switched Nd:YAG laser with a pulsewidth of 6 ns and wavelength of 532 nm is applied. A PDMS mold with 5/3 μm spacing grooves is simply a replica of a plane ruled reflection grating with 34° nominal blaze angle and 600 grooves/mm (10RG600-1850-2, Newport Corp). A 1 nm Ti/10 nm gold thin film is deposited on a 100 μm thick glass substrate. Fig. 3 demonstrates two-dimensional gold nanostructures fabricated by NPTA processes. After illuminating laser pulses with a fluence of 340mJ/cm$^2$, separated gold nanowires are formed as shown in Fig 3(a). By rotating the PDMS mold by a 90° and followed by second laser pulsing, gold nanowires are cut into nanosquares (Fig 3(b)). The shape of these isolated 2D nanosquares can evolve into 3D nanospheres by flood laser pulsing with a fluence of 600 mJ/cm$^2$. Molten nanosquares ball up due to surface tension driven shape evolution and form smooth nanospheres. Figure 3(c) and 3(d) show the SEM images of two types of periodic gold nanospheres arrays. The latter formed by rotating the PDMS grating mold with 120$^o$.

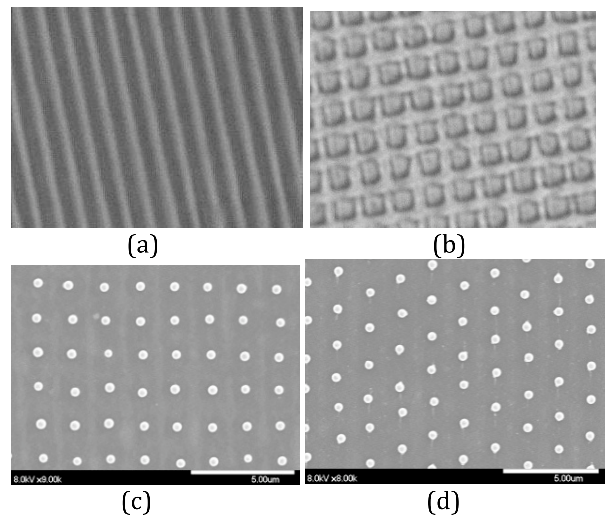


*Fig.3 Photothermal annealed periodic nanostructures (line-line and particle-particle spacing is 5/3μm). (a) gold nanowires; (b) 1×1μm$^2$ gold square before flood exposure; (c) 400 nm diameter gold nanospheres form orthogonal array after flood exposure; (d) Hexagonal gold nanosphere array (bar = 5μm).*

## CONCLUSION

We have demonstrated a novel near field photothermal annealing method for rapid fabrication of metallic nanostructures, such as nanowires, nanosquares, and nanospheres. By properly designing the phase-shifting mask, this method promises rapid laser fabrication of metallic nanostructures of any arbitrary shape.

## ACKNOLEDGEMENT

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