Large area laser parallel fabrication of user-defined nanopatterns by particle-lens arrays

Guo Wei, Zeng Bo Wang, Lin. Li, Zhu Liu, Boris Luk'yanchuk, and David J. Whitehead

Citation: ICALEO **2007**, N103 (2007); doi: 10.2351/1.5061164
View online: https://doi.org/10.2351/1.5061164
View Table of Contents: https://lia.scitation.org/toc/ica/2007/1
Published by the Laser Institute of America

LARGE AREA LASER PARALLEL FABRICATION OF USER-DEFINED NANOPATTERNS BY PARTICLE-LENS ARRAYS

Paper (N103)

Wei Guo[1,2], Zeng Bo Wang[1], Lin. Li[1], Zhu Liu[2], Boris Luk'yanchuk[3], David J. Whitehead[1]

[1]Laser Processing Research Centre, School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Sackville Street, Manchester, M60 1QD, UK

[2]Corrosion and Protection Centre, School of Materials, University of Manchester, the Mill, Manchester M60 1QD, UK

[3]Data Storage Institute, DSI Building, 5 Engineering Drive 1, Singapore 117608, Republic of Singapore

Abstract

Direct parallel writing nano-patterns over a large surface area is a challenging task. Techniques like electron beam and focused ion beam lithography are limited to particular applications because of low throughput and expensive setup. In this paper, an efficient and low-cost technique is reported on direct laser surface nanopatterning in the near-field region. By using angular incident laser beams with a self-assembled particle-lens array, flexible patterns have been produced by a few laser pulse exposures. It was demonstrated that hundred million parallel features can be written simultaneously in an area of one centimeter square.

Keywords: Laser nano-patterning, near-field effect, large area processing.

Introduction

Within the last two decades, surface patterning by laser-induced ablation, etching, deposition, and surface modification has been extensively investigated[1]. Normally, laser surface patterning was performed by focusing laser light directly onto the substrate or employing a projection mask, or by the interference of laser beams. Recently, near-field optics (NFO) has attracted great attentions in this area. NFO deals with optical phenomena where evanescence wave becomes significant and the sizes of the scattering objects are of the order of wavelength or smaller[2]. So far, several near-field patterning techniques exist: laser integrated scanning near-field optical microscopy (SNOM)[3-5], laser-assisted AFM/STM-tip patterning [6-9] and contacting particle-lens array (CPLA) patterning[10, 11].

Compared with SNOM and STM, the CPLA patterning technique has the advantages of simple setup, fast speed and large area processing. CPLA is demonstrated by means of two-dimensional lattices of micro-spheres that are formed by self-assembly. Such lattices have been used as micro-lens arrays that focus the light, which permits higher energy localization on the substrate below the particle[12]. The CPLA technique permits one to employ all types of light-induced processes for direct single-step surface patterning of millions of features with a few laser exposures.

However, the existing CPLA technique has a limitation of single step processing. After laser ablation, most of the particles were removed due to thermal deformation force and (or) ablative force exceeding the particle-substrate adhesion force[13]. The disappearance of the particle lens makes it impossible to fabricate complex patterns array other than dents array. To keep particles on surface for repeatable patterning, an angular laser beam scanning (ALBS) technique was demonstrated in our previous work[14]. By using this technique, different user-defined nanostructures like lines, curves and even more complex shapes were fabricated.

Experimental Procedures

A KrF excimer laser (GSI-Lumonic IPEX848) was used as the light source (wavelength λ =248 nm, pulse duration τ =15 ns and repetition rates from 1 to 10 Hz, non-polarized). The sample was a 20 nm semi-conductive $Sb_{70}Te_{30}$ thin film (refractive index n=1.80+2.07i) coated on polycarbonate substrate (n=1.57+0.12i). The threshold fluence of the thin film was about 20 mJ/cm^2. A close-packed monolayer of SiO_2 spheres (r= 500 nm) was directly formed onto the thin film surface over an area (5 x 5 mm^2) by its self-assembling. The spheres are commercially available suspension from Duke Scientific Cooperation. The laser energies used to ablate the materials were 100~ 300 mJ/pulse.

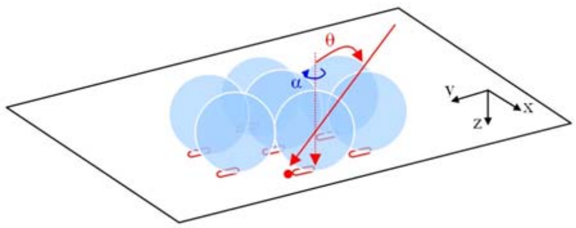

Figure 1. *Schematic diagram of the experimental configuration for direct laser writing of nano-line arrays on substrate surface*

Figure 1 shows the schematic diagram of the proposed technique for direct laser writing of an array of lines on surface. The laser beam was scanned in the YZ plane with an incident angle ***θ***. The intensity peaks on substrate were shifted away from the contacting point, which meant the ablative forces do not react with micro-spheres. Therefore, the spheres can be kept on surface after processing. As particles remained on surface, multiple steps processing are able to be applied.

To form a continuous line, single laser pulse was used for every small angle (π/36) scanned through the spheres. The scanning range was controlled within (-π/4, π/4). The normal incident beam was set to be the final step of the process to avoid removing the particles during the scanning.

The samples were then characterized by a Field Emission Gun Scanning Electron Microscopy (FEG-SEM; Philips XL32) and Atomic Force Microscopy (AFM; Vecco CP2).

Results

The optical near-fields around the particles were simulated by a rigorous particle on surface (POS) model, shown in Figure 2. The electromagnetic modes, including the evanescent modes, were taken into account in the model. The details of the theoretical formulation were described in the previous publication[15].

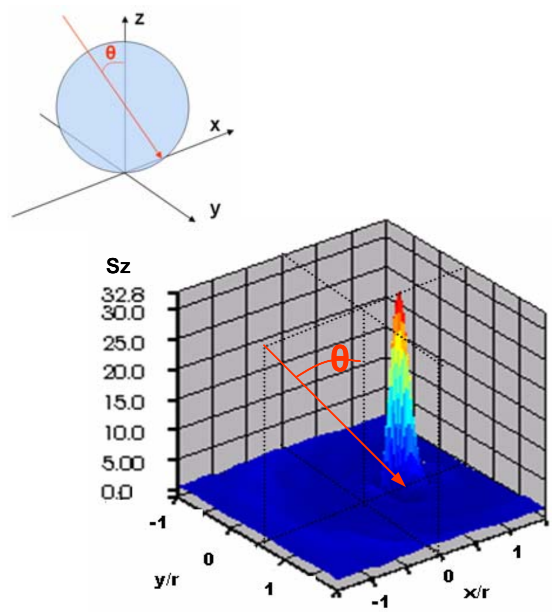

Figure 2. *Calculated Poynting intensity distribution Sz for λ = 248nm radiation with incident angle (θ=30º) under a* SiO_2 *sphere (n = 1.51) of radius (r=500 nm) on SbTe substrate (n = 1.80, k = 2.07).*

The evanescent wave modes played the main role and the total fields were enhanced. The peak enhancement was about 32.8 times and would decay rapidly with the increasing of angle ***θ***.

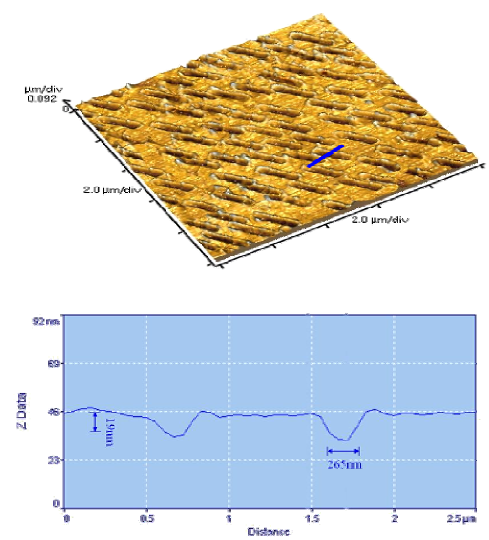

Figure 3. *AFM profile of ordered arrays of line structures, fabricated by ALBS technique.*

Figure 3 shows the 3D AFM profile of arrays of line-shape nanostructures fabricated by the proposed technique. The average line size was 1.2μm in length, 265nm in width and 20nm in depth.

It is important to note that the proposed technique is not limited to producing lines array. It is flexible to design the laser scanning path in different planes. For example, one can scan the beam with a fixed angle $\boldsymbol{\theta}$ but rotate the sample with angle $\boldsymbol{\alpha}$ in XY plane, which produced curves rather than lines.

Angle $\boldsymbol{\theta}$ controls the position of intensity peak point in radial direction, while angle $\boldsymbol{\alpha}$ moves it in circumferential direction. By turning $\boldsymbol{\alpha}$ with a small angle (π/36) each time and scanning $\boldsymbol{\theta}$ with relative angle, user-defined patterns can be easily fabricated, as illuminated in Figure 4.

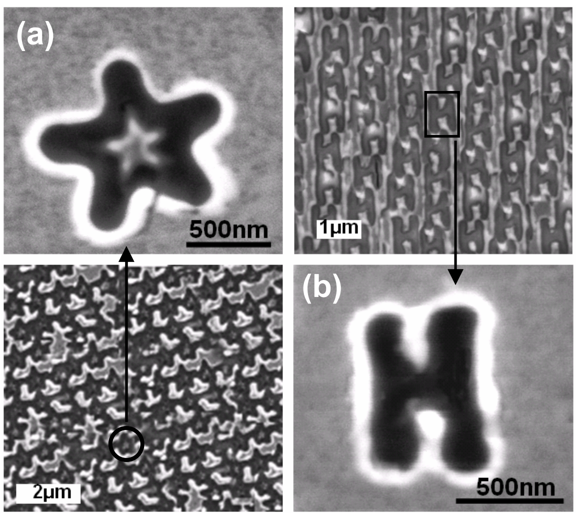

Figure 4. *SEM images of start-shape arrays (a) and H-shape arrays (b) produced by scanning beams with designed angles*

Both star-shape and H-shape features are about 1μm in X or Y dimension and 20 nm deep. A very small star-island (less than 300 nm) was remained after the beams scanned. Tens of millions of those features were generated by 72 laser shots in minutes.

Conclusions

We have developed an efficient laser technique to produce user-defined nanostructures on solid surface by scanning angular laser beam through a self-assembled micro-particle lens arrays. As final notes:

1. Each particle works as a near-field focusing lens and the focusing position can be precisely controlled by turning the incident angles.
2. About 10^8 features can be produced in an area of 1 cm^2 by tens of laser exposures. As large as the area of spheres monolayer is formed, this technique is able to be used to generate millions of patterns over a flat surface or even a curved surface.
3. The developed technique is simple, low cost and efficient which holds great potential for industrial applications.
4. Future work will be focus on improving the resolution of the features by using femtosecond laser and patterning materials with higher ablation threshold.

Acknowledgements

This research is funded by the UK North West Science Council (Grant No: N0003200). The authors want to thank the team members in NWLEC (www.nwlec.org.uk) project for their kind supports.

References

[1] Bäuerle, D.: Laser Processing and Chemistry. Springer, Berlin 2000.

[2] Girard, C., Dereux, A. (1996) Near-field optics theories. Rep. Prog. Phys. 59: 657-699.

[3] Betzig, E., Trautman, J.K. (1992) Near-Field Optics - Microscopy, Spectroscopy, and Surface Modification Beyond the Diffraction Limit. Science 257: 189-195.

[4] Riehn, R., Charas, A., Morgado, J., Cacialli, F. (2003) Near-field optical lithography of a conjugated polymer. Appl. Phys. Lett. 82: 526-528.

[5] Wysocki, G., Heitz, J., Bauerle, D. (2004) Near-field optical nanopatterning of crystalline silicon. Appl. Phys. Lett. 84: 2025-2027.

[6] Boneberg, J., Münzer, H.-J., Tresp, M., Ochmann, M., Leiderer, P. (1998) The mechanism of nanostructuring upon nanosecond laser irradiation of a STM tip. Appl. Phys. A 67: 381 - 384.

[7] Dickmann, K., Jersch, J., Demming, F. (1997) Focusing of laser radiation in the near-field of a tip (FOLANT) for applications in nanostructuring. Surface and Interface Analysis 25: 500-504.

[8] Jersch, J., Dickmann, K. (1996) Nanostructure fabrication using laser field enhancement in the near

field of a scanning tunneling microscope tip. Appl. Phys. Lett. 68: 868-870.

[9] Arias-Gonzlez, J.R., Nieto-Vesperinas, M. (2000) Near-f ield distributions of resonant modes in small dielectric objects on flat surf aces. Opt. Lett. 25: 782-784.

[10] Denk, R., Piglmayer, K., Bauerle, D. (2002) Laser-induced nanopatterning of PET using a-SiO2 microspheres. Applied Physics a-Materials Science & Processing 74: 825-826.

[11] Brodoceanu, D., Landstrom, L., Bauerle, D. (2007) Laser-induced nanopatterning of silicon with colloidal monolayers. Applied Physics a-Materials Science & Processing 86: 313-314.

[12] Hong, M.H., Huang, S.M., Luk'yanchuk, B.S., Chong, T.C. (2003) Laser assisted surface nanopatterning. Sens. Actuator A-Phys. 108: 69-74.

[13] Zheng, Y.W., B.S.Luk'yanchuk, Lu, Y.F., Song, W.D., Mai, Z.H. (2001) Dry laser cleaning of particles from solid substrates: Experiments and theory. J. Appl. Phys. 90: 2135-2142.

[14] Guo, W., Wang Z.B., Li L., Liu Z. (2007) Near-field laser parallel nanofabrication of arbitrary-shaped patterns. App. Phys. Lett. 90: 243101.

[15] Wang, Z.B., Hong, M.H., B.S.Luk'yanchuk, Y.Lin, Wang, Q.F., Chong, T.C. (2004) Angle effect in laser nanopatterning with particle-mask. J. Appl. Phys. 96: 6845-6850.

Meet the Author

Wei Guo received the MS degree in advanced manufacturing engineering from the University of Manchester, UK in 2004. Between 2004 and 2005, he was developing electro-chemical micro machining systems in Royce Laboratory. He is currently working towards the PhD degree at School of Materials, the University of Manchester. His main research interests include laser surface nano/micro patterning and its applications.