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Microdeposition of metals by femtosecond excimer laser

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Abstract

Microablation and transfer of thin metal films using ultrashort, ultraviolet laser radiation has been studied. A KrF excimer laser ($\lambda = 248$ nm) having 500-fs pulse duration is coupled to a high-power image projection micromachining workstation. The laser irradiation is focused onto thin Cr films through the supporting transparent quartz substrates. Single pulses are used to completely remove the metal film. The ablated material is transferred onto a receiving target glass substrate placed parallel to the source film. Experiments were conducted in a miniature vacuum cell under a pressure of 10^{-1} Torr. The distance between the source and target surfaces is variable from near-contact to several hundreds of microns. Serial writing of well-defined metal lines and isolated dots, is accomplished using the x–y sample micropositioning system. Optical microscopy and surface profilometry showed deposition of highly reproducible and well-adhering features of a few microns in width for a source–target distance in the neighborhood of 10 μm. The short pulse length limits thermal diffusion, thereby enabling superior definition of the deposited features. Metal patterns were also directly deposited via a parallel-mode mask projection scheme. In a first demonstration of this method, deposited diffractive structures were shown to produce high-quality computer-generated holograms. © 1998 Elsevier Science B.V.

Keywords: Femtosecond excimer laser; Microablation; Laser-induced forward transfer; Microdeposition

1. Introduction

The laser-induced forward transfer (LIFT) technique utilizes pulsed lasers to remove thin film material from a transparent support. The film is precoated on a quartz substrate and is transferred using a single laser pulse onto a receiving substrate placed parallel to the source film. The LIFT process was shown by Bohandy et al. [1,2] to produce direct writing of 50 μm-wide Cu lines by using single nanosecond excimer laser pulses (193 nm) under high vacuum (10^{-6} Torr). Wagal et al. [3] have reported deposition of diamond-like carbon films by the LIFT technique in a UHV chamber using Nd:glass laser. Several other studies [4–6] have reported direct writing of 20 μm-wide metal lines under air or helium ambient conditions using nanosecond laser pulses. The dynamics of the laser ablation transfer (LAT) of micron-thick coatings effected by near-IR ($\lambda = 1064$ nm) 23 ps laser pulses has been studied by Sandy Lee et al. [7] via an optical microscope with picosecond temporal resolution. This work showed that the

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velocity of the ejected material is 0.75 Mach and that the use of picosecond optical pulses results in a reduction of the laser fluence threshold by one order of magnitude, relative to 100 ns long pulses.

The ability to deposit patterns, spots and lines, with micrometer-order resolution, has applications in the microelectronic fabrication, as well as in the area of optoelectronics. Artificial texturing and engineering of sensitive parts is an effective approach to overcoming stiction problems in microelectromechanical system (MEMS) surfaces, thereby improving tribological performance and component lifetime. Conventional methods of surface patterning are chemical vapor deposition (CVD), plasma CVD and sputtering deposition which by nature are not location-selective. Among the advantages of the LIFT technique over the conventional methods is that there is no need for complicated and expensive gas handling/high vacuum systems, and that the properties of the surface are not influenced by either the process, or the purity of the deposition.

Whereas the flexibility of LIFT techniques is appealing in a variety of applications, several problems, among which notable is the remelting of the transferred material by the trailing part of the laser pulse are often encountered in experiments with nanosecond and longer laser pulses. Such phenomena should be limited by using ultrashort laser pulses, allowing superior control of the structure and definition of the transferred material. Consequently, the aim of this work is to demonstrate high resolution microablation and pattern microdeposition of thin Cr films by means of femtosecond ultraviolet radiation.

2. Experiment

The material used as 'source' for the microdeposition experiments were Cr films of 400, 800 and 2000 Å in thickness, on transparent quartz wafers. The Cr films were prepared by sputtering and e-beam evaporation and were of uniform thickness and structure; scratch and scotch-tape tests showed good adhesion. Glass (Corning) was used as 'receiver target surface'. The distance between the source and target surfaces was variable from near-contact to 1000 μm with a 5 μm accuracy. The source-target pair was placed in a miniature vacuum cell under a pressure of 10^{-1} mbar driven by a rotary pump. This miniature cell was fixed onto a computer controlled x–y translation stage, allowing a maximum 25 mm $\times$ 25 mm movement, by means of piezoelectric motors (Burleigh, Inchworm model), having a 50 nm resolution determined by their optical encoders. Thus, serial writing of metal lines and isolated dots was achieved, as well as complicated computer-generated diffractive structures.

A schematic diagram of the excimer laser microdeposition setup is depicted in Fig. 1. The ablation laser was a distributed-feedback dye laser-based femtosecond excimer laser system (248 nm, 13 mJ pulse energy, 500 fs pulse duration (FWHM), 1–10 pulse/s repetition rate, 30×10 mm^2 beam size). The laser beam was focused onto the target surface through a high-power image projection micromachining system [8], based on the inverse microscope principle which has been modified to achieve projection of a mask on a large reduction basis ($\times 30$) onto

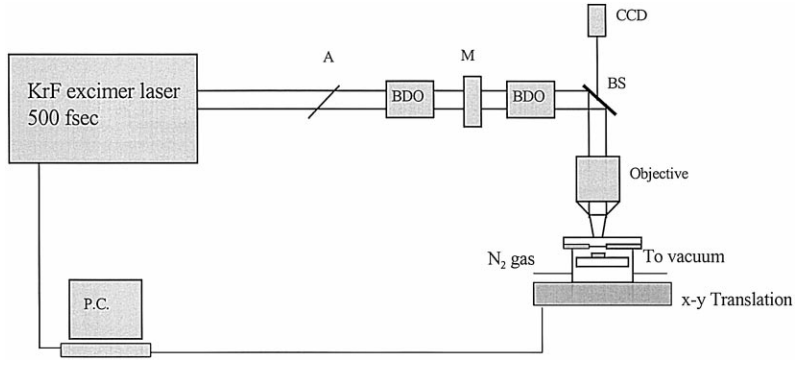

Fig. 1. Schematic diagram of the optical set-up for excimer laser microdeposition. A: attenuator, BDO: beam delivery optics, M: mask, BS: beam splitter, CCD: camera.

the target. The estimated depth of focus of the system is 2 μm. Experiments were conducted for the parameters listed in Table 1 below. During the deposition process, the target area can be viewed through an imaging system, including a CCD camera and microscope ocular lenses. The characterization of the deposited samples was performed using optical microscopy, scanning electron microscopy and surface profilometry (Perphometer model).

3. Results

The optical absorption in the source film, affects the threshold fluence above which, a single pulse leads to the film removal and transfer onto the receiver surface. The absorption depth of Cr at the 248 nm wavelength is 220 Å, implying that transmission of the excimer laser light through even the thinner (400 Å thick) source film is negligible. The forward ablation threshold, is defined as the energy density value at which complete film material ablation and transfer in the direction of propagation of the laser beam is effected by a single pulse. This threshold is influenced by the thickness of the source film. No deposition from the 2000 Å thick source Cr film was obtained by a single excimer laser pulse at the maximum energy density (500 mJ/cm^2) used in this experiment. The forward ablation thresholds of the 800 Å and 400 Å source films, were correspondingly 100 mJ/cm^2 ($\pm$20%) and 80 mJ/cm^2 ($\pm$20%), while the best quality of the deposited dots in terms of uniformity was obtained for the thinner

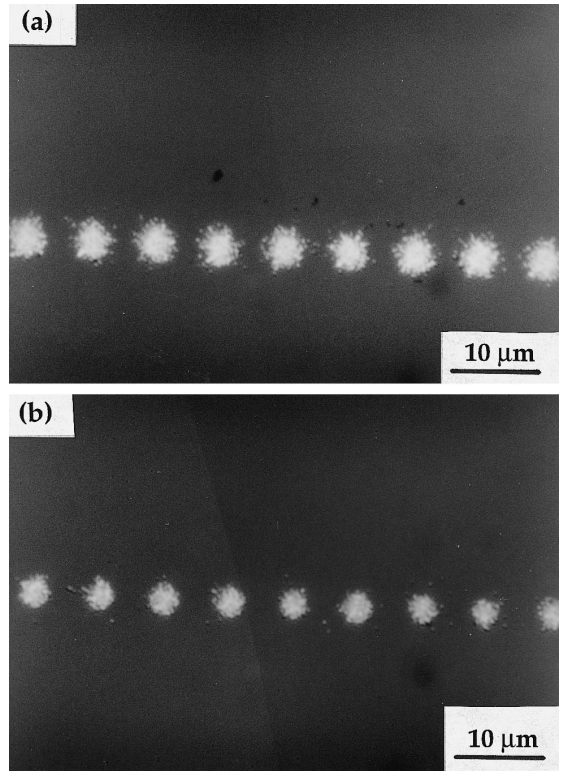

Fig. 2. Optical microscope pictures of isolated Cr dots deposited on glass by femtosecond laser microdeposition (magnification $\times$1200, scale: 10 mm corresponds to 4.5 μm). The target source was 400 Å Cr. The UV illuminated area is 4 μm$\times$4 μm and the energy density varies as follows: (a) 339 mJ/cm^2 and (b) 248 mJ/cm^2.

Cr source film, minimizing thermal effects and the extent of the damaged (melted) area. Fig. 2a and b

Table 1
Summary of the experimental parameters

Target thickness (Å)	Receiver surface	Laser source	Energy density (mJ/cm^2)	Pixel size (μm $\times$ μm)	Distance target–receiver
Cr/quartz	Glass (Corning 7059 type)	248 nm 500 fs (FWHM) 4 Hz	50	2 $\times$ 2	from near-contact to 500 μm with with 20 μm step
400			70	4 $\times$ 4	
800			140	8 $\times$ 8	
2000			220	16 $\times$ 16	
			310	32 $\times$ 32	
			420	64 $\times$ 64	
			510		
			550		

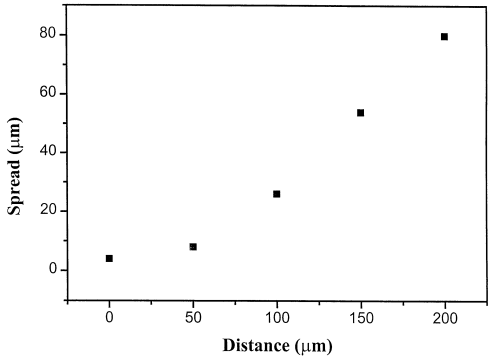

Fig. 3. Plot of the width of deposited lines as a function of the gap between the source film and receiver target surfaces. The energy density was 500 mJ/cm^2.

shows the morphology of dots deposited from a 400 Å source at the respective energy densities of 339 mJ/cm^2 and 248 mJ/cm^2. The size of the transferred pixel was 4 μm × 4 μm. The spread of the ablated material was also studied by varying the distance between the source and target surfaces from near-contact to 500 μm. Fig. 3 shows the width of deposited Cr lines as a function of this distance.

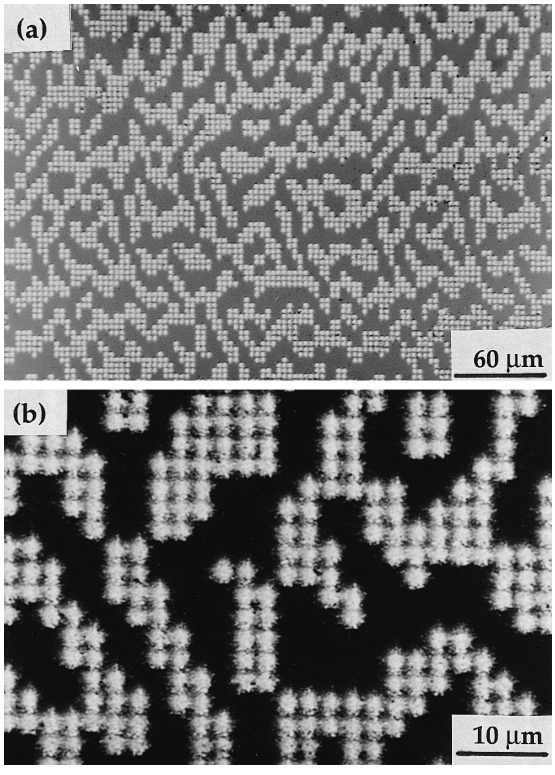

Fig. 4. Optical microscope pictures of a computer-generated holographic pattern produced by Cr microdeposition on glass. The target source was 400 Å Cr. The pattern consists of 64×64 pixels with pixel size 4 μm×4 μm. (a) far view (magnification ×200), (b) close-up view (magnification ×1200).

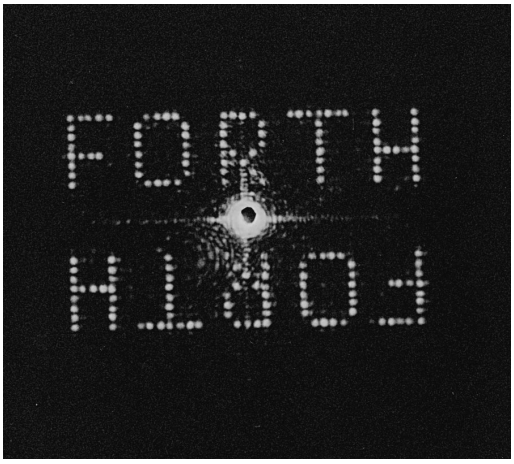

Fig. 5. Reconstruction of the femtosecond excimer laser microdeposited computer-generated hologram using a He–Ne laser.

Computer-generated holograms were fabricated as a demonstration of this process. The microdeposition was done either by serial writing (pixel by pixel) of the diffractive pattern, or by directly projecting a master hologram mask on the source film surface. Fig. 4a and b depicts a diffraction pattern produced by the deposition of 400 Å thickness target source Cr on glass at an energy density of 372 mJ/cm^2 and using a pixel size of 4 μm × 4 μm. The reconstructed results are shown in Fig. 5. Under illumination with red laser light (633 nm), the pattern 'FORTH' is visible. It is worth noting that experiments with a nanosecond excimer laser as the ablating beam did not yield deposited features of quality comparable with the femtosecond laser results. While pursuing other applications, investigations are also focused on the fundamental physical mechanisms of metal ablation, film removal and transfer.

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