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MICROFABRICATION OF OPTICALLY ACTIVE InO_X MICROSTRUCTURES BY ULTRASHORT LASER PULSES

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Direct printing of compound InO_x microstructures by Laser Induced Forward Technique (LIFT) using a femtosecond UV laser will be presented. LIFT is a technique enabling the direct controlled transfer of thin film materials between substrates. An ultrashort UV pulsed laser has been used to transfer molecular InO_x material onto glass substrates in order to form optical diffractive structures. The LIFT process enables reproduction of the oxide's structural and physical properties. Subsequent ultraviolet illumination by a 325 nm HeCd laser has induced dynamic refractive index changes of the InO_x grating. This optical behavior is similar to the holographic recording behavior of InO_x thin films. The use of laser-based methods, in the fabrication of optically activated microstructures, opens new application possibilities in the area of optoelectronics.

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1. Introduction

The laser-induced forward transfer (LIFT) technique [1, 2] utilizes pulsed lasers to remove thin film material from a transparent support and deposit it onto a suitable substrate. The thin film is precoated on a quartz plate ("target") and is transferred using a single laser pulse onto a receiving substrate placed parallel to the target film. The ability to deposit patterns, spots and lines, with a μm order resolution, has applications in the microelectronics 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 micro-electro-mechanical system (MEMS) surfaces, thereby improving tribological performance and component lifetime. Conventional methods of surface patterning are Chemical Vapour Deposition (CVD), Plasma CVD and sputtering which by nature are not location-selective.

In this work we demonstrate the high quality microdeposition of compound InO_x material by means of direct materials transfer using femtosecond ultraviolet radiation. The present approach, exploits all advantages over conventional methods, including simplicity in terms of vacuum handling, deposition purity, position selectivity and high accuracy submicron pattern transfer.

2. Experimental

The material used as the "target" in the microdeposition experiments was InO_x films [3, 4], of 100 to 400 nm thickness, on transparent quartz wafers. The InO_x films were prepared by Pulsed Laser Deposition (PLD) and sputtering and were uniform and well adhering. Glass (Corning type 7059) and Si (100) were used as "substrate surfaces". The distance between the target and the substrate surfaces was variable from near contact to 1000 μm with a 5 μm accuracy. The target substrate pair was placed in a miniature vacuum cell under a pressure of 0.1 mbar driven by a rotary pump. This miniature cell was fixed onto a computer controlled x-y translation stage, allowing a maximum 25 mm × 25 mm movement, by means of piezoelectric step motors, with 50 nm positioning resolution. Serial writing of grating lines dots is achieved, as well as the fabrication of complicated computer generated optical diffractive structures.

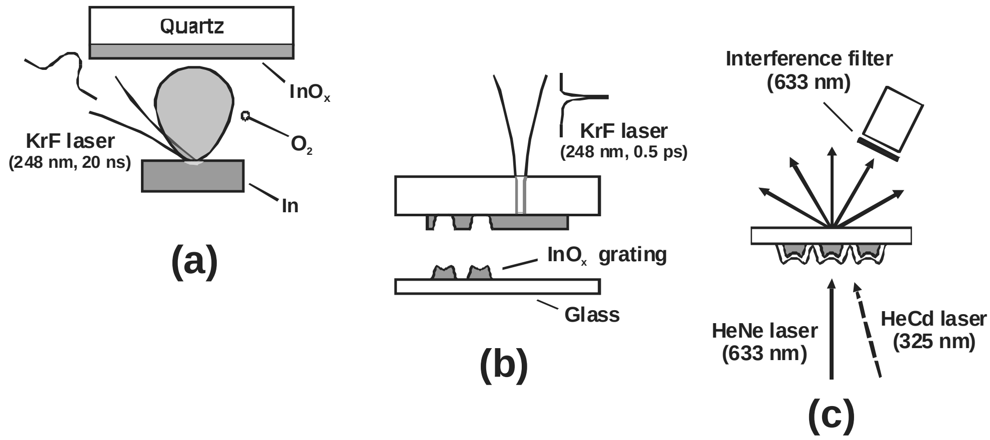

Fig. 1. Outline of InO_x grating development and testing (a) pulsed laser deposition of the InO_x targets, (b) InO_x grating microprinting, and (c) optical diffraction and grating activation.

The schematic diagram of the excimer laser microdeposition setup is previously described in details [5]. The laser source is a distributed-feedback dye laser-based fs excimer laser system (248nm, 13 mJ pulse energy, 0.5 ps pulse duration, 1-10 pulse/sec repetition rate). The laser beam was focused onto the target surface through a large-reduction ratio (÷30) micromachining system [6].

The characterization of the deposited samples was performed using Optical Microscopy, Scanning Electron Microscopy, Atomic Force Microscopy and X-Ray Diffractometer.

Complicated diffractive optics such as binary phase computer generated holograms were fabricated for that purpose, demonstrating the potential of this technique. 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 target film surface.

Additionally, we have fabricated InO_x thin-films on fused-silica plates by reactive PLD using pure indium metal and oxygen as outlined in Fig. 1(a). Experimental details and structural analysis of these films have already been presented in Ref. [7]. InO_x growth rates of ~0.01-0.05 nm/pulse are achieved and films of thickness in the range of 100 nm to 400 nm exhibit excellent uniformity, high optical transparency in the visible and good holographic performance in the UV. The above films have been subsequently used as the target materials in the laser microprinting operation outlined in Fig. 1(b). In some experiments dc magnetron sputtered films have also been used. The LIFT technique of the InO_x target films was applied to perform grating structure on the glass substrate. Relatively long slit features are projected demagnified by (÷30) to produce deposits of lateral dimensions ~5 μm × 100 μm. The maximum laser energy fluence was 400 mJ/cm^2 on target and a high-precision step-and-repeat operation was applied to form simple grating microstructures.

3. Results and discussion

The structures were analysed with x-ray diffractometry and the results were in full agreement with our previous work [5]. Fig. 2 depicts the Scanning Electron Micrograph of a computer generated holographic pattern produced by InO_x microprinting on glass.

All grating structures are transparent and exhibit permanent diffraction effects as evidenced by the monitoring He-Ne laser probe beam as shown in Fig. 1(c).

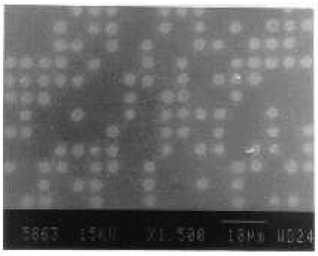

Fig. 2. Scanning electron micrograph of a computer generated holographic pattern produced by InO_x microprinting on glass.

To demonstrate grating activation we irradiated the structure using a HeCd UV beam. Diffraction efficiency was monitored using a HeNe laser. Both the HeNe laser (12 mW power at 633 nm) and the HeCd laser (38 mW at 325 nm) were incident nearly normal to the substrate surface either unfocused or loosely focused. A fast shutter was used in the UV beam to alternate between the ON and OFF activation states. An atomic force microscope (AFM) image of part of a typical InO_x grating is shown in Fig. 3. Fourier analysis of its profile reveals a dominant period of ~10 μm that is in agreement with this grating design. Typical feature height values fall also within the design range of 150-200 nm.

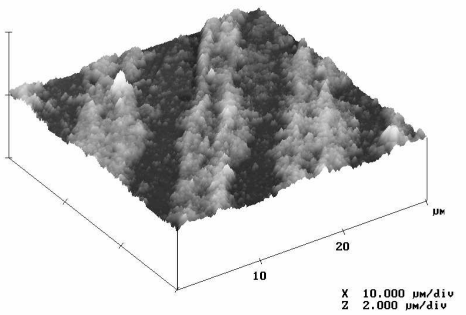

Fig. 3. Atomic force microscope (AFM) image of a small portion of a typical InO_x grating.

The optical activation experiments have been performed in the temperature range of 10 ^oC - 55 ^oC using a stabilized Peltier element. The ±1-diffracted order beam intensity was recorded for consecutive activation cycles and the absence of fatigue effects has been verified. The ON and OFF states were established for long time periods to ensure relaxation of all processes involved. For unperturbed gratings of ~180 nm nominal average relief height, the net (uncorrected for loss) background (dark) diffraction efficiency values are typically $\eta_{\pm1}\approx5\%$ and remain constant in time to about ± 0.1%. Within the temperature range examined a maximum ±8% reversible and temperature dependent variation of diffraction efficiency of the grating has been observed during the ON and OFF activation states. Neither dependence on light polarization, nor any effects due to the He-Ne laser beam were observed. Higher diffraction orders exhibited a similar dynamic behaviour.

4. Conclusion

In conclusion optically activated InO_x surface relief microstructures have been developed through laser based methods. Optical activation of these structures has been demonstrated by using UV laser irradiation. The overall behaviour shows close similarities with the previously reported holographic recording on InO_x thin films. The origin of the effects is not fully understood and further study is under way. The use of laser-based methods, in the fabrication of optically activated micro- and nano-structures, opens up new and exciting application possibilities in the area of the optoelectronics.

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