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Advances in ultra short pulse laser based parallel processing using a spatial light modulator

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- Invited Paper -

Abstract

Presented here are latest advances in ultra short pulse laser based parallel processing using a spatial light modulator (SLM), which has the potential for use in high throughput precision patterning of photovoltaic and other device layers. Ultra short laser pulses allow selective material removal with minimal energy density, while here a computer-generated hologram driven reflective SLM is used to transform a single beam into multiple beamlets for increased process throughput. Based on this technique, the precision patterning of silicon, titanium, thin film ITO and metal on flexible and glass substrates is demonstrated and the benefits and current limitations discussed.

Keywords: ultra short pulse laser; laser ablation; laser patterning; parallel processing; spatial light modulator

1. Introduction

Laser patterning is a key industrial process for use in the manufacture of photovoltaic devices such as organic light emitting diode (OLED) displays, solid-state lighting foils and solar cells. Ultra short pulse lasers are of particular interest as they may enable selective ablative removal of material layers with minimal energy density, hence avoiding damage or unwanted effect to adjacent layers. Since the output pulse energy of commercial laser sources currently far exceeds that required for single beam processing, parallel processing with multiple beams could provide a novel route for scaling up process throughput and reducing manufacturing costs. The approach discussed here uses a reflective liquid crystal on silicon

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spatial light modulator (SLM), driven by fast computer-generated holograms, to split a parent laser beam into a number of beamlets and digitally manipulate their position and intensity on or over the target area.

Spatial Light Modulators (SLMs) are adaptive optical devices that can modulate the properties of an incoming optical wavefront, such as phase, amplitude or polarisation. Since their introduction in the 1980's [1], SLMs have attracted increasing attention in many research areas that include temporal pulse shaping [2], holographic optical tweezers [3, 4], wavefront correction [5, 6], spatial beam shaping [7, 8] and laser parallel processing [9-11]. A common implementation of a SLM is the liquid crystal (LC)-based SLM. The basic principle of operation of these devices is that the phase change of the light polarized along the crystal's extraordinary axis can be precisely controlled by the variable refractive index of LC materials. Since LC-based SLMs usually modulate light in response to either optical or electrical inputs, they can be classified as two major categories: namely, optically and electrically addressed SLMs. An optically addressed SLM (or optically addressed light valve), which is constructed of a continuous photosensitive layer on top of modulating material, has the ability to modulate a light beam using another beam; however, its manufacturing cost is relatively high. On the other hand, an electrically addressed SLM comprises a pixelated structure that is manipulated electrically so as to modulate the local optical wavefront at each individual pixel. The advantage of this device type is the capability of direct interfacing between optical and electronic units. However, its drawbacks are the lower light utilization efficiency (owing to the dead zone between the electrodes) and diffraction losses caused by the pixelated structure.

Parallel processing using diffractive multiple beams generated by a SLM has been shown to increase the throughput and efficiency of ultra short pulse laser processing. By synchronisation with a scanning galvanometer, further flexibility in micromachining has been demonstrated [9-12]. Since many industrial applications would require that all the diffractive beams have a good identity to ensure a consistent processing, the uniformity of the diffractive pattern is a significant parameter. As reported by Curtis et al [13], the uniformity of the diffractive pattern is not only affected by the algorithm used to calculate CGH [14, 15], but also the geometric design of the diffractive pattern. A slight spatial disordering of periodic and symmetric patterns can significantly reduce intensity variations among each of the desired diffractive peaks. In the literature, a better uniformity of diffractive pattern has been demonstrated by improving the CGH calculation algorithm, e.g. adding iterative calculations to minimize the uniformity error of the computationally reconstructed diffractive peaks [16, 17], or by taking account of the intensity distribution of the irradiated laser pulse and the spatial frequency response of the SLM [16, 19-20]. However, there has been little work studying experimentally the effect of different geometric designs of diffractive pattern uniformity. In this paper, multiple laser beams parallel processing including selective ablation and large-area processing are demonstrated. In addition, beam shaping with an SLM is also presented. A study into the effect on uniformity of varying the geometric pattern design is also given.

2. Experimental

The ultra short pulse laser system used for the present research was a custom made Nd:VAN seeded regenerative amplifier (High-Q IC-355-800ps, Photonics Solutions). Figure 1 shows the schematic of the experimental setup. The output laser beam (t_p = 10ps, λ = 1064nm) passed through a half wave plate used for adjusting the linear polarization direction, a beam expander (M $\approx \times 3$) and, after reflection on mirrors 1, 2 and 3, illuminated a reflective SLM oriented at <10 degree angle of incidence. A 4f-optical system was formed from A to D to remove the unwanted 0-th order beam. The modulated beam then entered a scanning galvanometer with f = 100mm flat field of f-theta lens (Nutfield), providing an agile focusing system. Substrates were mounted on a precision 5-axis (x, y, z, p, q) motion control system (Aerotech)