Nanoscale materials processing by means of modulated short pulse lasers

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Focus control of industrial laser processing applications has been gaining strong attention due to the variety of applications, ranging from the ICT devices, automotive electronics and photovoltaic cells. The authors have used Bessel beam modulation of the lateral spatial profile of the propagating laser pulse of ns-pulse Nd:YAG laser to achieve order-of-magnitude fine laser scribing of transparent conductive oxide films. Bessel beam as various advantages over the Gaussian beam profile due to its smaller beam diameter of its peak and longer focal depth. Due to its robustness and low introduction cost, ns-pulse Nd:YAG lasers are widely used in various industrial applications. FTO (fluoride doped tin oxide) films deposited on glass substrate are used. Fundamental wavelength of a Nd:YAG laser is used for the experiment. Grooves were fabricated by successive irradiation of single shot with constant irradiation pitch.

At first, the liquid optical device was introduced to see the effect of beam modulation. Original Gaussian beam of the spatial profile perpendicular to the beam propagating direction is modulated to obtain the Bessel beam. The results showed that the groove line width of about 5 μm and the focal depth of about 400 μm is achieved despite of the relatively low beam quality compared with the solid optics.

Solid optics is then introduced where newly proposed optics composition is used to obtain very long focal depth and to allow easier optical adjustment. The results showed 11.5 mm focal depth with the scribing groove width of down to 2.3 μm.

Irradiation direction has strong influence on the single shot scribing depth. The substrate-side irradiation exceeds the film-side irradiation in scribing depth of about 50% to 100% deeper value in the case of Gaussian beam. The difference, however, reduces significantly in the case of Bessel beam. Coupled beam propagation and thermal analysis is conducted to examine the difference, and it is confirmed that the film-side irradiation of Gaussian beam leads to significant plasma shielding of pulse irradiation. Bessel beam irradiation from the film-side, however, reduces the plasma shielding to mitigate the problem. Film-side irradiation is in general favor of its simplicity and robustness. Investigations also revealed the substrate-side irradiation scribing mechanism, where previous works proposed the light absorption at the interface to lead to fracture and lift-off of the film. Current study proposes quasi-homogenous absorption of laser light along film thickness to initiate ablation to cause the film removal.

Further study is under way to investigate various issues regarding the beam modulation applications and the nonlinear phenomena in the target material to meet the demands of the pulse laser processing in manufature.

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