Femtosecond Laser Printed Microoptics in Hydrogenated Amorphous Silicon

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Conventional optics (e.g. lenses or mirrors) manipulates the phase via optical path difference by controlling thickness or refractive index of material. Recently, a promising type of optics emerged which exploits geometric phase shift, when a lightwave is transformed by parameter other than optical path difference, e.g. polarization. Here, wavefront is modified by introducing spatially varying anisotropy and is a result of Panchatraman-Berry phase [1]. Theoretically any phase pattern can be achieved solely by means of geometric phase with efficiencies reaching 100% [2]. This allows continuous optical phase shifts and without phase resets, in stark contrast to conventional elements, wherein phase profiles are encoded as discrete optical path variations in refractive index or thickness, limiting performance. The geometric phase optics is a promising alternative for controlling and manipulating light, but it stumbles on the lack of adequate fabrication technology.

Here we demonstrate that ultrafast laser assisted nanocrystallization of a-Si:H films is accompanied by the formation of laser-induced periodic structures. The observed pattern with the sub-wavelength ($\Lambda \approx \lambda/3$) modulation of local refractive index exhibits a dichroism and enhanced form birefringence ($\Delta n \approx$-0.5–-0.6). The induced birefringence is two orders higher than commonly observed in uniaxial crystals or femtosecond laser nanostructured silica glass (-2×10^{-3}–-5×10^{-3}) [3] allowing implementing functional micro-optical elements with thickness of less than 300 nm by exploiting geometrical phase. Both dichroism and giant birefringence can be controlled by changing laser writing parameters adding extra dimensions to polarization sensitive printing (Fig. 1), which is technologically attractive for applications in fields of flat optics [2], optical data storage [4] and security marking.

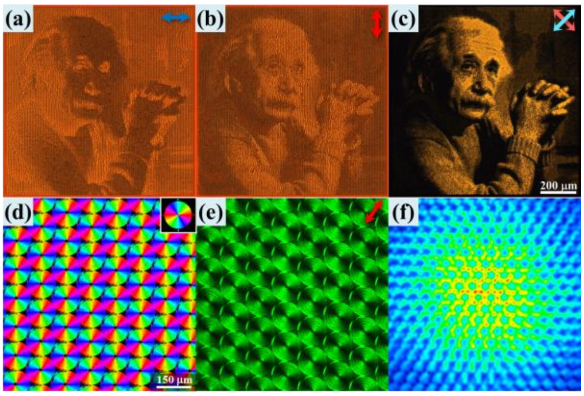

Fig. 1 (a)–(c) The polarization sensitive Einstein's portrait imprinted in a-Si:H film by femtosecond laser nanostructuring. Arrows indicate (a) parallel, (b) perpendicular and (c) cross-polarized polarization states used for optical transmission imaging. (d)–(f) Array of radially polarized optical vortex micro-converters for circular incident polarization imprinted in a-Si:H film. (d) Pseudo colors indicate the direction of slow axis. (e) Linearly polarized optical transmission image of array of converters illuminated by 546 nm wavelength circularly polarized light. (f) Beam intensity profile of Nd:YAG cw laser after the converter within propagation distance of 50 cm.

Experiments were carried out with a 300 nm thick a-Si:H film deposited on a silica glass substrate by the plasma-enhanced chemical vapour deposition (PECVD). The film was irradiated with a mode-locked Yb:KGW ultrafast laser system operating at 1030 nm at 100 kHz repetition rate. Pulse duration was set to 360 fs. The beam was focused on the film surface via 0.13 NA–objective lens resulting in fluence of 0.2 J/cm^2. Writing speed was set to 0.2 mm/s with interline/pixel size of 5 µm. Translating the sample with the synchronous rotation of linear polarization, Einstein's portrait (Fig. 1(a)–(c)), as well as the array of radially polarized optical vortex micro-converters (Fig. 1(d)–(f)), were imprinted by encoding the information via a laser beam's polarization.

References

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978-1-4673-7475-0/15/$31.00 ©2015 IEEE