The Science and Art of Ultrafast Laser Writing

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Femtosecond laser writing in transparent materials has attracted considerable interest due to new science and a wide range of applications from laser surgery, 3D integrated optics and optofluidics to optical data storage [1]. Two decades ago it was discovered that under certain irradiation conditions subwavelength periodic structures with record small features of 20 nm, can self-organize in the volume of fused quartz [2-4]. On the macroscopic scale the self-assembled nanostructure behaves as a uniaxial crystal with negative birefringence.

The control of the polarization azimuth allows direct writing of flat optics elements with spatially variant anisotropy, which exploits the geometrical or Pancharatnam-Berry phase and in particular S-waveplates for polarization shaping (Fig. 1a) [5]. The applications of S-waveplates ranges from material processing and optical trapping to extreme UV generation [6].

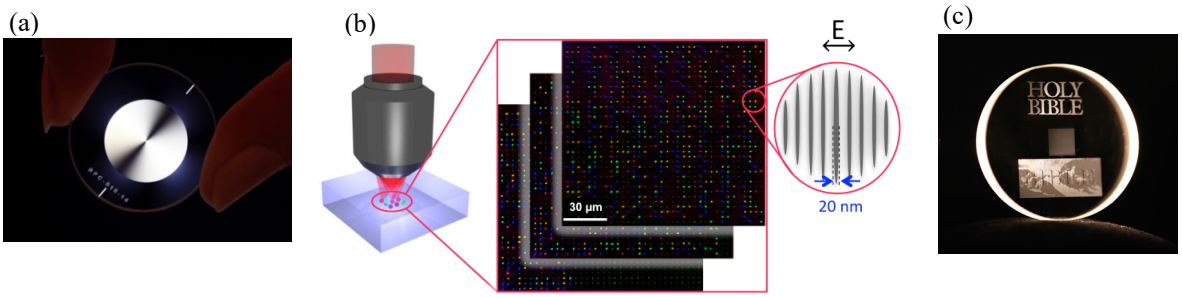

Figure1: (a) Femtosecond laser written S-waveplate in cross-polarized light. (b) 5 D optical storage. Each voxel contains a self-assembled nanograting oriented perpendicular to the light polarization. (c) Eternal copy of King James Bible imprinted in silica glass.

More recently ultralow-loss birefringent optical elements including UV retarders and geometrical phase lenses and prisms have been demonstrated exploiting new type of anisotropic nanoporous modification in glass, referred to as Type X [7]. unprecedented

A remarkable phenomenon was also discovered, referred to as quill or calligraphic laser writing, which reveals strong dependence of the material modification, in particular the self-assembled nanostructures, on the writing direction relative to the pulse front tilt [8]. Moreover, coupling of polarization with the angular dispersion, has been demonstrated as a new degree of freedom in ultrafast laser material processing [9].

It was also explored for the optical data storage in the bulk of silica glass, in addition to three spatial coordinates, using two independent parameters of induced form birefringence, the slow axis orientation (4^{th} dimension) and the strength of retardance (5^{th} dimension) (Fig. 1b). The slow axis orientation and retardance can be independently controled by the polarization and intensity of the femtosecond laser beam. The data optically encoded into five dimensions can be successfully retrieved by quantitative birefringence measurements. The storage allows hundreds of terabytes per disc data capacity and thermal stability up to 1000° and is vital step towards an internal archive (Fig. 1c) [10]. Project Silica is exploiting 5D optical storage in glass for the first-ever storage technology designed and built from the media up, for the cloud [11].

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