Multi-Shot Laser Ablation and Digital Micromirror Device Mask Translation for Sub-diffraction-limit Machining Resolution

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Digital Micromirror Devices (DMDs) can offer rapidly generated, bespoke intensity modulation masks for image-projection-based laser-machining. Recent work has shown repeatable sub-micron feature patterning [1], with proposed applications in the medical sciences and photonics. While DMDs can offer rapid patterning, with ~32kHz switching speeds available [2], they are not yet efficient reflectors at <300nm, thus limiting machining resolution to the diffraction limit at the near-visible wavelengths and above.

Here, we demonstrate a technique for the laser machining of structures that have a resolution below the diffraction limit of a single mask exposure, via DMD-based spatial intensity modulation. While the diffraction limit applies to the resolution of a structure machined via a single projected intensity profile (in this case, a single laser pulse), a second (different) intensity profile can be used to modify the structure in order to produce a final pattern that would be impossible to create in a single exposure. The schematic in Fig. 1 shows this approach, where once a single diffraction-limited structure has been machined, a second diffraction-limited structure can be machined arbitrarily nearby, such that the sample region between two adjacent machined areas contains dimensions below the diffraction limit. Without addressing material limits on feature width, using N pulses could lead to features with a spacing that is N times smaller than the diffraction limit.

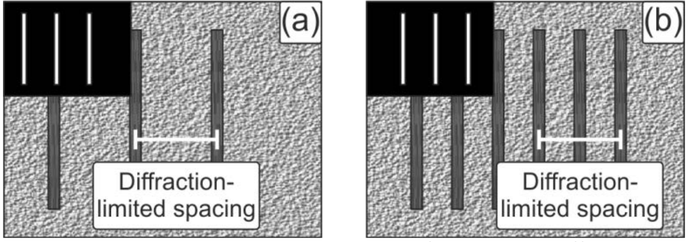

Fig. 1 A schematic of the technique. (a) A single projected intensity profile can ablate diffraction-limited features (shown as darker rectangles). (b) A second, subsequent and translated intensity profile enables machining between these features, hence appearing to 'beat' the diffraction limit. Insets show the projected spatial intensity profiles for each pulse.

Here, the intensity profile of incident pulses from a Ti:sapphire amplifier (800nm, 150fs), was spatially shaped by the DMD (Texas Instruments, DLP7000), a 768 by 1024 array of 13.6μm square mirrors, and imaged via a 50x objective with 0.55 NA, giving a diffraction limited machining resolution of 727nm. Fig. 2 shows a pattern sequentially ablated with multiple different projected intensity profiles in 200nm thick BiSnTe, with a spatial periodicity of 650nm (hence lower than the diffraction limited resolution value of 727nm given earlier). Features as narrow as 160nm were also observed in 50nm thick GeSbTe. The sub-wavelength positional accuracy of sequential projected intensity profiles on the sample was achieved through translation and/or rotation of the intensity mask on the DMD itself, avoiding the need for expensive nanometre precision translation/rotation stages; a single-mirror translation on the DMD corresponded to a 90nm translation at the sample. We aim to produce finer features via tuning of material ablation thresholds, hence allowing closer packing of features and significantly greater resolution than possible with a single exposure.

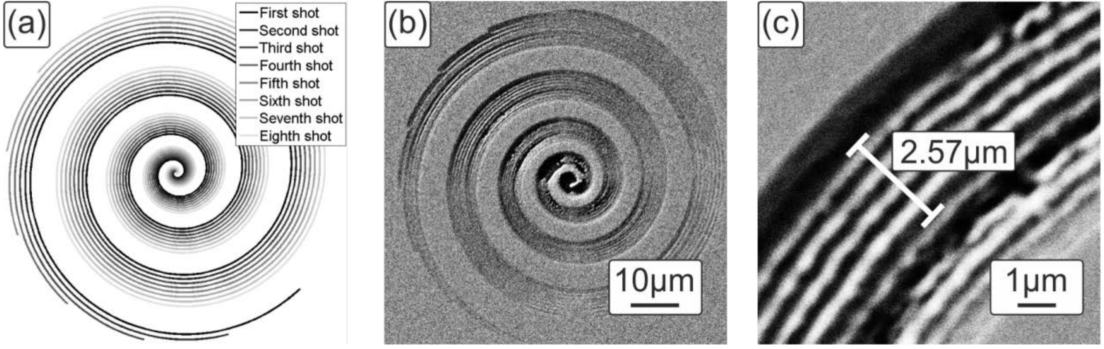

Fig. 2 Spirals ablated in 200nm thick BiSnTe (a) a greyscale-coded schematic showing the rotation of the spiral between pulses (b) an SEM of the final pattern (c) a small region of the pattern showing a periodicity of 650nm.

References

[1] B. Mills, M. Feinaeugle, C. L. Sones, N. Rizvi, and R. W. Eason, "Sub-micron-scale femtosecond laser ablation using a digital micromirror device," J. Micromech. Microeng., **23**(3), 035005 (2013).

[2] Texas Instruments DLP Discovery 4100 datasheet, http://www.ti.com/lit/er/dlpu008a/dlpu008a.pdf, accessed 6th Jan 2015.