Tailored Femtosecond Bessel Beam Processing
- Application to Through Si Vias for 3D Si ICs -

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The steady pursuit of high-performance, low-power-consumption, and small-footprint microelectronic devices has made three-dimensional integrated circuits (3D ICs) an attractive replacement for conventional 2D ICs. One of the major challenges to realize 3D ICs is the fabrication of high-aspect-ratio through-silicon vias (TSVs), which is a key technology for the 3D assembly of Si ICs [1]. Here, we propose to employ femtosecond (fs) 1.5-μm Bessel beams for high-speed fabrication of high-quality, high-aspect-ratio through Si holes for TSV application. By performing laser ablation in air using conventional Bessel beams, nearly taper-free through Si holes with diameters of ~3 μm in 50-μm-thick Si substrates, which corresponds to aspect ratios of ~17, can be created. However, severe damage with a concentric structure was produced around created holes due to relatively high sidelobe energy in the Bessel beam. To suppress the severe damage, a fs Bessel beam is tailored by using specially designed binary phase plates (BPPs) for the first time. We theoretically and experimentally demonstrate that this method can generate a fs laser beam with a ~6-μm lateral spot size and ~400-μm focal depth, while reducing the sidelobe ratio (SLR) to ~0.6%, which is much smaller than the ~16% SLR for a conventional Bessel beam. The developed technique successfully eliminates sidelobe-induced damage to ensure high-quality fabrication of through Si holes with a high aspect ratio [2]. Specifically, 2D array of through Si holes with an aspect ratio of ~15 in a 100-μm-thick Si substrate without any sidelobe damage was fabricated as shown in Fig. 1. Our technique is potentially applicable for 3D assembly in the manufacturing of 3D Si ICs.

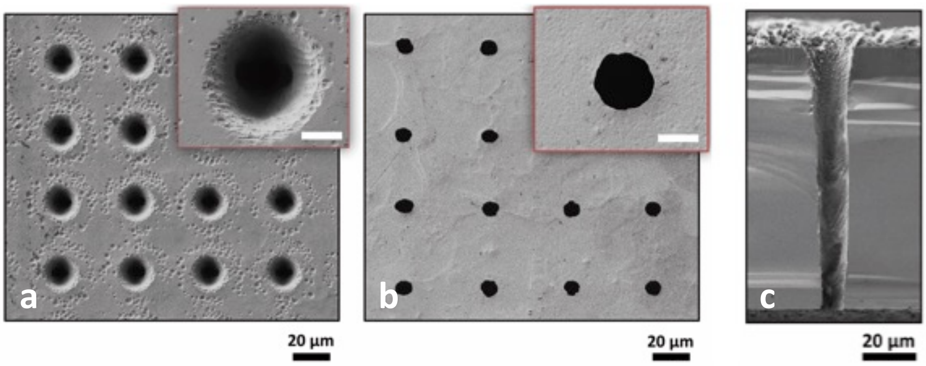

Fig.1 SEM images of (a) front surface, (b) rear surface, and (c) cross-section of through Si holes fabricated in 100-μm thick Si substrates by Bessel beam tailored with a BPP. The scalar bars in the inset are 5 μm.

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[2] F. He, J. Yu, Y. Tan, W. Chu, C. Zhou, Y. Cheng, and Koji Sugioka, Sci. Rep. **7**, 40485 (2017).