Characterization of strain fields around Through-Silicon Vias by second-harmonic scanning microscopy

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3D integration is currently a forefront technique for achieving high transistor integration density while reducing inter-chip RC delay and power consumption. Among numerous 3D integration designs, metallic "through-silicon vias" (TSVs) are a promising strategy for interconnecting stacked devices. However, the large mismatch in coefficients of thermal expansion between metal and silicon compromises thermal-mechanical reliability. Moreover, thermal strain introduced during TSV fabrication can induce defects that degrade carrier mobility within the strain field, voids within the metal interconnect, and cracking of the Si wafer [1]. A strong need therefore exists for fast non-invasive methods of characterizing the strain fields surrounding TSVs. Here we show that scanning SHG microscopy is sensitive to these strain fields. Even though SHG is forbidden to lowest order from unstrained bulk Si, strain gradients break the centrosymmetry of the diamond-structure lattice, creating a second-order dipolar optical nonlinearity [2].

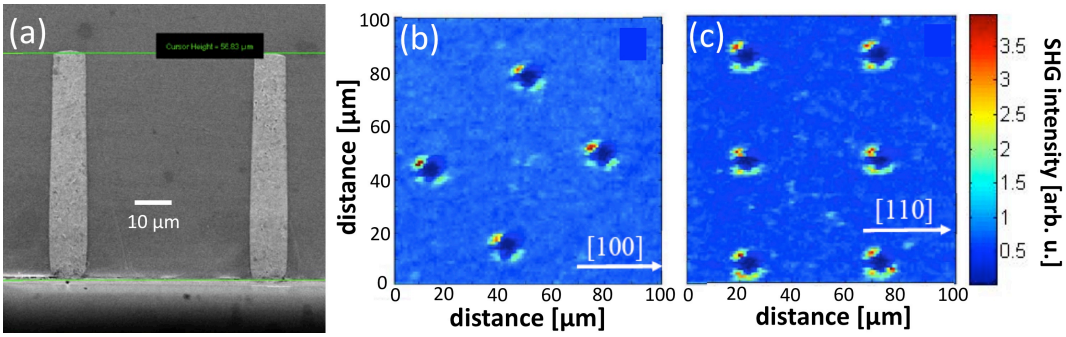


Fig. 1 (a) SEM micrograph of TSV cross section. **(b)** SHG scanning micrograph in p_{in}/s_{out} polarization configuration, with plane of incidence parallel to [100] crystallographic direction; (c) same as (b), but with plane of incidence parallel to [110].

Sample preparation followed a standard procedure [3]: TSV trenches were fabricated by reactive-ion etching, followed by plasma-enhanced chemical vapor deposition of SiO_2 side walls. Copper electro-plating filled the holes. A chemical-mechanical polish left ~10 µm diameter circular Cu wires, shown in cross section in Fig. 1a. For SHG scanning microscopy, incident laser pulses (775 nm, 100 fs) were focused at 45° incidence to a 2 µm spot, and the sample was scanned in a raster pattern while SHG was monitored. Fig. 1(b) shows results for s_{in}/p_{out} polarization configuration. Enhanced SHG is observed within a narrow annulus around each TSV in three lobes of unequal intensity separated by 90°. When the sample is rotated 45° [Fig. 1(c)], the SHG anisotropy retains its orientation with respect to the optical plane of incidence rather than rotating with the crystal. Similar enhancements, but with different anisotropies, are observed with p_{in}/p_{out}, s_{in}/p_{out} and s_{in}/s_{out} polarizations. These polarization-dependent SHG anisotropies will be presented in the light of phenomenological SHG theory [2] and simulations [1] of TSV-induced strain fields.

[1] Ryu SK, Lu KH, Jiang TF, Im JH, Huang R and Ho PS, "Effect of thermal stresses on carrier mobility and keep-out zone around Through-Silicon Vias for 3D Integration," *IEEE Trans. Dev. Mat. Reliability* **12**, 255 (2012).

[2] Govorkov SV, Emel'yanov VI, Koroteev NI, Petrov GI, Shumay IL and Yakovlev VV, "Inhomogeneous deformation of Si surface layers probed by SHG in reflection," *J. Opt. Soc. Am. B* ***6***, 1117-1124 (1989).

[3] Garrou P, Bower C and Ramm P, *Handbook of 3D Integration: Technology Applications of 3D Integrated Circuits* (Wiley-VCH 2008).