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doi:10.1017/S1431927610058733

Microsc. Microanal. 16 (Suppl 2), 2010

High Throughput Sample Preparation and Analysis using an Inductively Coupled Plasma (ICP) Focused Ion Beam Source

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The Focused Ion Beam (FIB) has become ubiquitous for site-specific cross sectioning and other sample preparation activities in the semiconductor failure analysis lab, as well as in many other research and industrial settings. Such systems use a gallium liquid metal ion source (Ga-LMIS) as the source of the ions, providing a typical beam current range of 1 pA to 20-65 nA, with a maximum material removal rate by sputtering of ~10^3 μm^3/min for silicon at 60 nA of beam current. However, some larger structures seem beyond the reach of FIB techniques using such standard sputtering rates. For example, in semiconductor packaging, solder bumps and Through-Silicon-Vias (TSVs) which have length scales of ~100 µm, would generally be considered prohibitively large for a routine FIB cross section, resulting in mill times of hours or 10s of hours, or more.

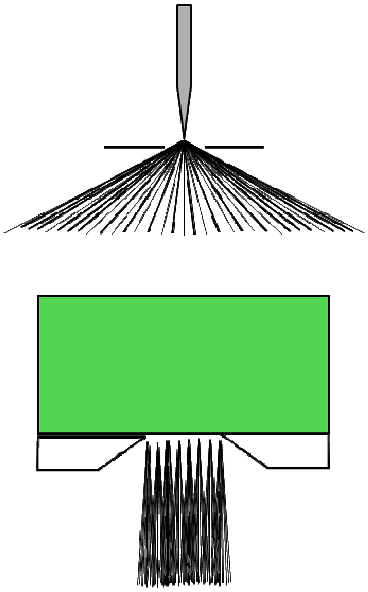
Above several 10s of nA of ion beam current, the Ga-LMIS ion beam performance becomes considerably degraded due to the ion optical properties of the source and focusing lenses. For such a high current regime new ion source technology is needed and the inductively-coupled plasma (ICP) source is a promising candidate [1,2]. While the LMIS is a point source with high brightness, the ICP is a broad source with high angular intensity, making it more suitable for high current operation (see Fig. 1). These optical properties mean that while the ICP source based FIB system does not produce as fine an ion beam as the LMIS-based FIB at low beam currents - with approx 50 nm possible compared to < 5 nm with a LMIS-based FIB - the ICP is far superior at high beam currents enabling up to several µA of ion beam current for fast material removal. The cross-over in beam spot performance between the LMIS and ICP is around 20-50 nA, above which the ICP offers the better performance. In addition, the ICP allows for a wide range of possible ion species; with Xe currently being used as the milling species of choice due to its higher mass (e.g. the sputter yield for Xe is 1.6 times higher per ion than Ga when milling Si) and favorable ion source performance parameters [1]. Therefore using a 1 µA Xe beam can have an overall milling rate for silicon some 80 times higher than a Ga beam operating at 20 nA, with enhancements of over 200 times seen for materials like Cu and epoxy [2].

Two applications of the ICP based FIB are shown in Figs. 2, 3 and 4. In Fig. 2 nearly 1 million cubic microns of material was removed in less than 20 minutes to expose an accelerometer through its packaging. Figs. 3 and 4 show the cross-sectioning and imaging of copper TSVs, with both images also being acquired with the same ICP source-based FIB [3].

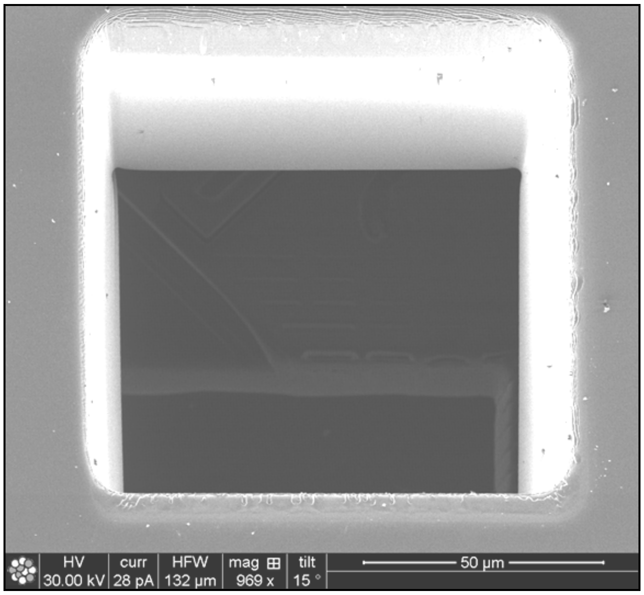
References

[1] N.S. Smith et al., “High brightness inductively coupled plasma source for high current focused ion beam applications”, J. Vac. Sci. Technol. B 24 (6) (2006), pp. 2902–2906.
[2] S. M. Kellogg et al., “A system for massive, rapid material removal for device analysis in monolithic 3D integrated circuits”, Presented at EIPBN Conference (2009)

[3] Part of this work has been funded by the European ENIAC JEMSIP-3D project (120016)



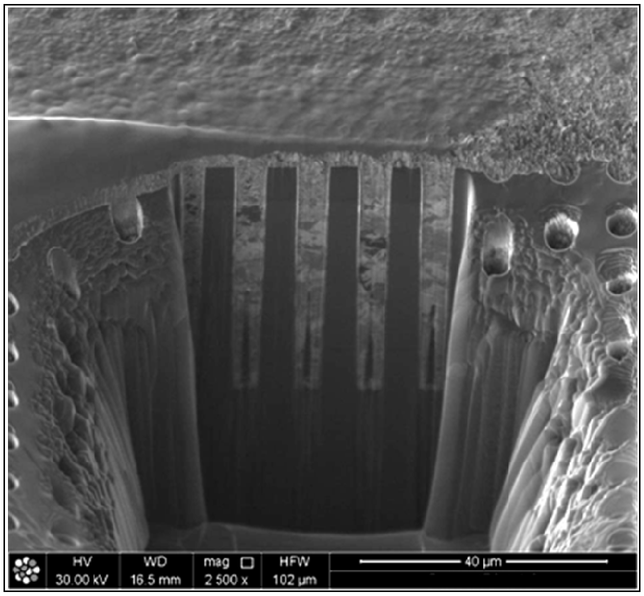
1.



2.

FIG. 1. Comparison of LMIS (top) and ICP (bottom) ion sources. The LMIS is a point source with high brightness, but low angular intensity. In contrast, the ICP is a broad source, with lower brightness, but high angular intensity.

FIG. 2. Tilted view into an access window milled in MEMS device packaging to expose accelerometer. Hole volume of $7\ 10^5\ \mu m^3$ was milled in 18 mins by 1.5 µA Xe plasma-FIB ion beam.



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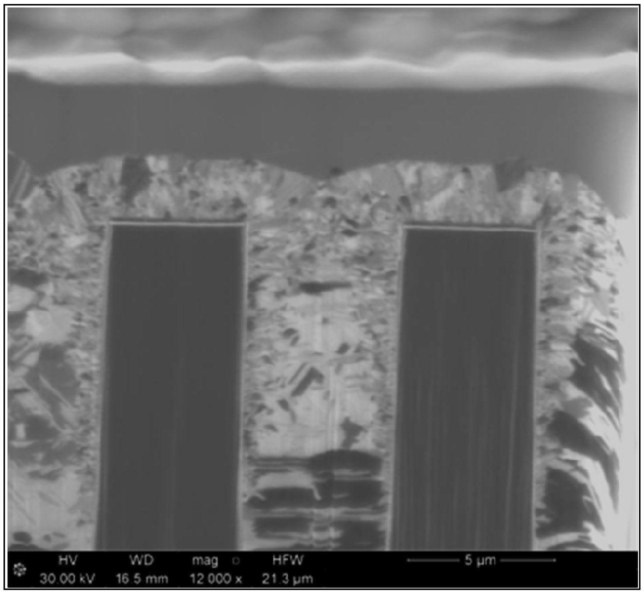

4.

FIG. 3. Tilted view of cross-sectioned TSVs, each having diameter 5µm, depth 50µm, copper filled

FIG. 4. Detail of the TSV top with copper fill, with tungsten protection layer on top of the copper