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X-ray Computed Tomography Studies on DSA Formed Vertical Nanocylinders Containing Metals for 3D-LSI Applications - Characterization Technique Dependent Reliability Issues

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Abstract

We report the x-ray computed tomography (X- CT) experimental results obtained on directed self-assembly (DSA) formed nanocylinders containing metals with width in the range of 30 nm. We compare the X-CT results obtained on DSA formed metal nanowires inside deep Si trenches with the conventional morphological characterization techniques such as scanning electron microscope (SEM) and transmission electron microscope (TEM). It is found that X-CT is much more reliable than the SEM and TEM, especially when analyzing the 3-dimensional nano-sized structures.

Keywords: TSV, DSA, nano-wire, X-ray CT

1. Introduction

Sporadic demands for high-performance computing is expected sooner than later as one move on to the AI (Artificial Intelligence), IoT (Internet of Things), etc, In both AI and IoT regime, for high-performance computing one needs an enormous amount of I/O (input/output) interconnections without compromising IC (Integrated Circuit chip) area and power consumption. One way to realize this is by 3D-integaration (vertical stacking of integrated chips) of several functional IC chips, and interconnect them using vertical interconnects. By doing so not only enhances the computation performance due to smaller RC (resistive-capacitive) delay, but also makes less power hungry with smaller form-factor owing to the minimal wiring. The rate of data-transmission is also an important factor, which is mainly governed by number I/O counts.

To be less power hungry it is inevitable to send and receive the several data sets at a relatively slower speed but extremely in parallel (refer fig. 1), and this parallel processing is only achieved through enhancing the number of vertical I/Os in 3D-LSI. Previously we have proposed and demonstrated to fabricate nano-sized vertical nano-cylinders with and without metal from nano-composite containing diblock-copolymers and metal containing salts or nano-dots [1-4], where we have fabricated 30-nm-sized vertical nano-cylinders with aspect ratio value in several hundreds.

In this work, we report the morphological features of such nano-cylinders characterized through X-CT method to obtain the reliable data, and made comparative analysis between X-CT and conventional SEM/TEM methods.

2. Experimental

The nanocylinders were formed by DSA reaction inside the deep Si trenches and the details can be found elsewhere [4]. As formed nanocylinders containing Fe as well as Sn metals were characterized by Zernike-phase contrast and absorption contrast X-CT using BL47XU at Spring8 Also conventional morphological characterization using SEM, TEM.

3. Results and Discussion

(i)Deleterious role of mechanical polishing: Shown fig. 2 and 3 are cross-sec. SEM images observed for DSA formed nanocylinders from PS-b-PMMA and Fe salts, and the samples were prepared by mechanical polishing using Silica slurry. It is clear from fig. 2 that these mechanical polishing does induce cracks in Si matrix, and these cracks propagate across the DSA formed nanocylinders. Further such cross-sectional polishing leaves polishing residue as well slurry on the polished surface of the nanocylinder polymers, which obstruct the nano-meter scale analysis.

(ii) Damage caused by FIB sample preparation: Fig. 4 and 5 depict the FIB induced damage and artifacts in the TEM analysis. Since nanocylidners were formed by organic co-polymers, low-temperature FIB were used for sample preparation. These thermal shock does induce cracking in the polymers, and these cracks run all across the sample volume both laterally and longitudinally. In addition the FIB induced artifacts clearly obscured the scallop information as well as the actual depth of TSV, and hence misleading results.

(iii)Sample independent X-CT results: Fig. 6 reveals SEM image of the free-standing TSV filled with DSA formed nano-cylinders used for X-CT analysis, and the samples were prepared by Si-DRIE using SF6 gas. The X-CT results are depicted in fig. 7. Fig. 7(a) and (b) respectively show the presence of DSA-formed Fe nano-wires laterally and longitudinally, respectively. In the case of Sn metals, it showed the agglomeration of Sn particles all along the TSV depth.

In summary we were able to observe DSA-formed nanocylinders with Fe without compromising the pixel resolution and free from sample damage or foreign particles. Conventional SEM/TEM sample preparation affects the observation results by either sample damage (cracking) or foreign particle residue.

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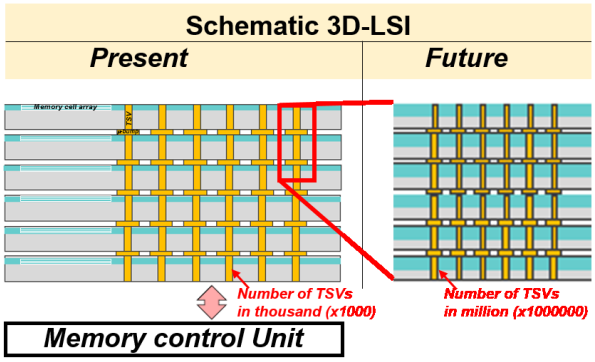


Figure 1. Schematic representation of present and future 3D-memory containing vertical interconnections having the diameter in µm scale (present) and nm scale (future).

References: [1] T. Fukushima *et al,* 3D-IC2016; [2] M. Murugesan *et al*, SSDM2017. [3] M. Murugesan *et al*, LTB-3D 2017. [4] M. Murugesan *et al*, ECTC 2017.

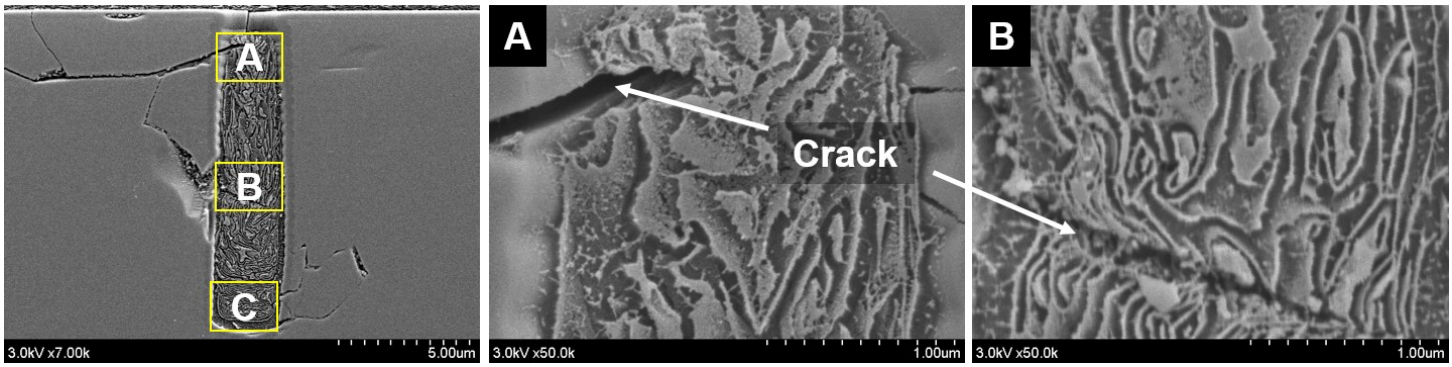


Figure 2. SEM revealing the mechanical damage induced in the cross-sec. sample during mechanical polishing.

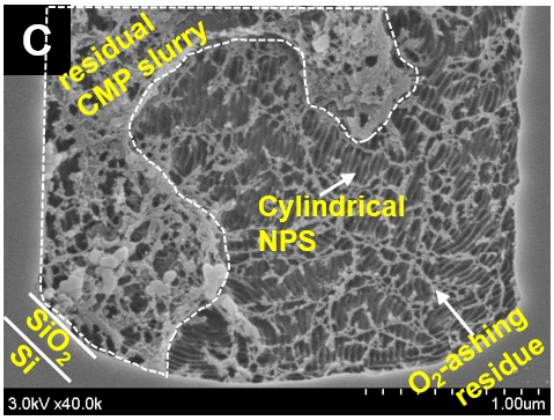


Figure 3. SEM revealing the presence of CMP residue as well as slurry over the mechanically polished X-sec. sample.

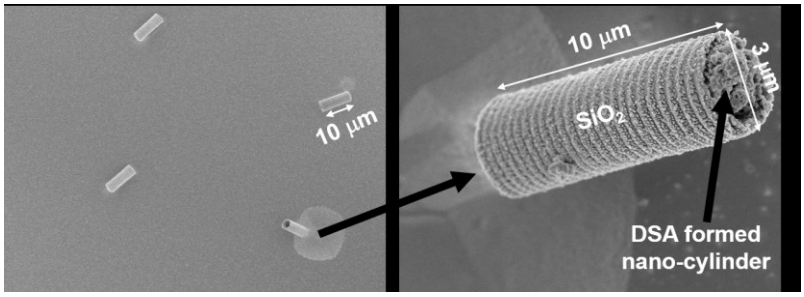


Figure 6. SEM images of defect-free free-standing 10 µm-long TSV sample containing PS-b-PMMA diblock-copolymer nano-cylinders with Fe and Sn metals analyzed by X-CT method, fabricated by Si-DRIE process.

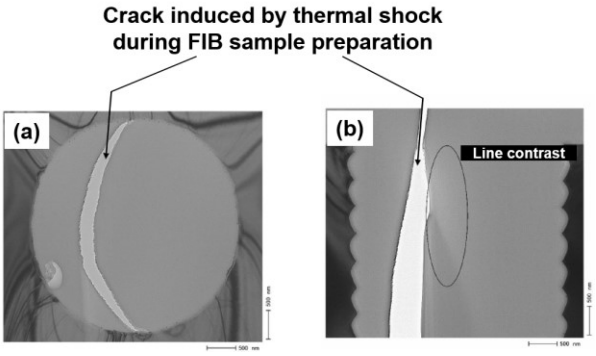


Figure 4. SEM image revealing the cracking of cross-sec. sample prepared by FIB process for SEM and TEM analysis.

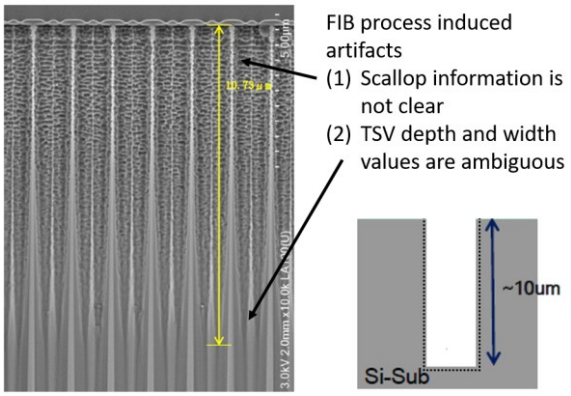
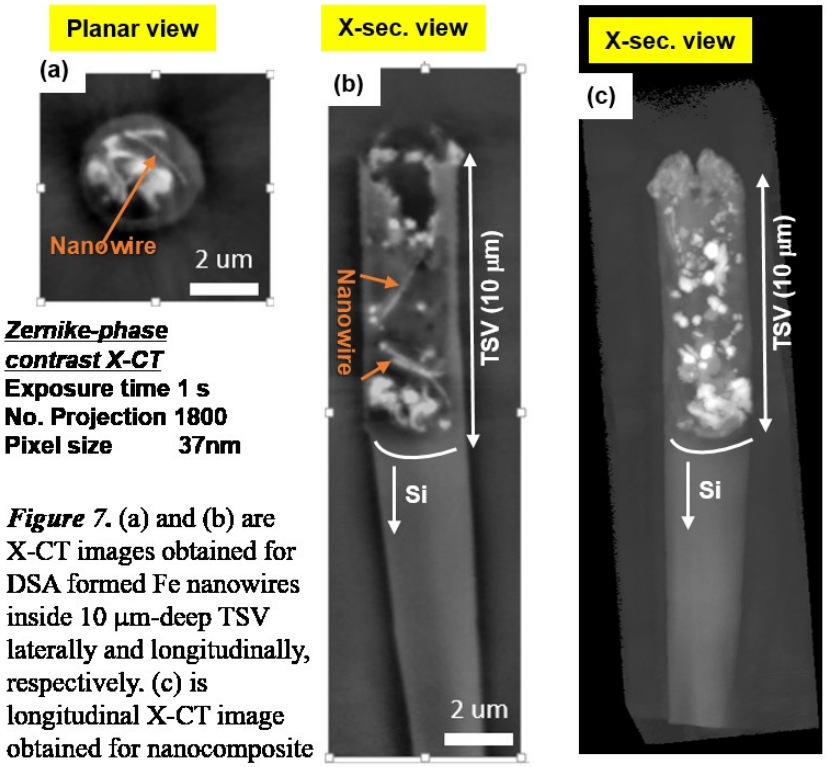


Figure 5. FIB induced artifacts resulting into difficulties in deciding the actual Si-trench depth.



Zernike-phase contrast X-CT
Exposure time 1 s
No. Projection 1800
Pixel size 37nm

Figure 7. (a) and (b) are X-CT images obtained for DSA formed Fe nanowires inside 10 µm-deep TSV laterally and longitudinally, respectively. (c) is longitudinal X-CT image obtained for nanocomposite containing PS-b-PMMA di-block co-polymers and Sn metal nanodots after DSA reaction at 280 °C in vacuum. Fe salts forms 2-3 µm-long nanowires both in lateral and longitudinal direction. Whereas the Sn nanodots got segregated all along the TSV.