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Enlarging the Nanocylinder Size for Through-Si-Via Applications

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Abstract

The successful formation of nanoscale cylindrical structures inside the Si deep trenches opens up the possibility of these nanocylinder (NC) structures can be used as TSVs in the future 3D-LSI/3D-IC. An attempt was made to increase the width of the NC, in order to decrease the resistance of NC interconnect when it is employed in 3D-stacking. It is confirmed that the width of the NC has large dependency on di-block copolymer (DBC) chain length (in other words, the molecular weight), and the higher the molecular weight the larger the width of the NC.

Keywords: Nanocylinder (NC), Si trench, 3D-Integration Technology, Directed Self-Assembly (DSA)

In order to overcome the RC delay in the conventional ULSI circuit (owing to the inevitably long metal lines), 3D-integration technology was developed and gathered momentum. In 3D-LSIs or 3D-ICs, through Si via (TSV) with (or without) metal microbumps are used as an electrical interconnections between the stacked tiers. The present benchmark size for the TSVs/microbumps is in submicron level. Although these submicron interconnects for 3D-LSIs/ICs are realizable with today's technology, but comes with cost. With more and more digital applications evolving around the artificial intelligence and neuromorphic computing, the demand for scaled interconnects will be ever increasing.

Hence it is worth to explore a method for the fabrication of interconnects at nanometer (nm) scale, which is simple and less expensive. Recently, it has been reported recently that the self-formation of regular array of nanoscale features inside the deep Si trenches [1]. Wherein the diblock-copolymers (DBC) were subjected to undergo directed-self- assembly (DSA) to form both lamella and cylindrical features at nm level, and the size of the cylinder was around 20 nm. However, it is also important to have lower resistivity fort the scaled interconnects. ***Thus, in this work, we have tried to increase the width of the nanocylinder (NC) formed by DSA from 20 nm to somewhere between 70 ~ 80 nm.***

Shown in Fig. 1 is the schematic process flow diagram for the formation of NCs inside the Si deep trenches. The DBC with PS:PMMA ratio as 2:1 were used for the formation of cylindrical structures inside the deep Si trenches that were fabricated by the conventional Bosch etch. The diameter and depth of these trenches were 3 μm and 10 μm, respectively. Followed by conformal coating of either SiO_2 or polyimide as a dielectric material along the side wall as well at the bottom of the Si-trenches was carried out. Subsequently the nanocomposite containing DBC and metal nanoparticles in a suitable solvent (such as PM thinner, Pyridine, Toluene, etc.) were charged into the Si deep trenches via spin coating. In order to charge the trench completely and void-free, lot of optimization was carried out mainly for the parameters such as viscosity of the nanocomposite, rotation speed during spin coating, nanocomposite volume, etc. We have arrived to the following numbers namely 50~60 micro-liters of nanocomposite for the chip area of 100 mm^2 and 1500 rpm for 30s. As spun chips were heated at hotplate for removing the excess solvent before annealing in the box oven. The annealing temperature was set to 340 ˚C, so that the temperature of the chip was ~300 C for few to several hours. In order to confirm the formation of NC inside the Si trench, we carefully prepared the cross-sectional (X-sec.) samples for high-resolution scanning electron microscopy (SEM) analysis.

Fig. 2 (Top view SEM images) reveals that the PS-b-PMMA DBCs were rearranged into NCs after DSA reaction at ~ 300 ˚C. Shown in Fig. 3 is the X-sec. view of SEM images obtained on the sample shown in fig. 2. It can be easily confirmed that the as formed NCs via DSA in the Si trenches were running parallel to each other from trench top to the near bottom of the trench. These NCs were tightly packed as well as neatly arranged. The size of the NCs were in the range of 20 - 25 nm and the molecular weight of PS was 57k. Either these NCs itself can be used as a template for the vertical interconnection formation, or replacing the core of the cylinder (i.e. PMMA forms the cylinder matrix) by electroplated metal after etching out. Our primary aim is to enlarge the size (width) of these NCs, in order to reduce the resistance of interconnects after the NCs were metallized. For that we have increased the molecular weight of the PS to 140k from 57k, by keeping the PS:PMMA ratio constant, 2. The X-sec. SEM images on PS (140k) sample (fig. 4) unambiguously reflect the increase in the size (width) of the NC to 80-70 nm from 20 nm for PS(57k). This nearly four-fold increase in the NC size well supported by the 3x increase in the molecular weight of the PS.

Also, the solvent fraction of the nanocomposite (i.e. metal nanoparticles and DBC in solvent), anneal temperature, and annealing period are found to play an important role in the formation as well as the size of the NC, and will be discussed at the presentation.

In summary, both planar- and cross-sectional view SEM data reveal that the formation of around 80 nm-width cylinders inside Si deep trench structures, which opens up the possibility of these nanocylinders be used for the formation of ultra-scaled TSVs with very high density in 3D-LSI integration.

[1] Fukushima et al, Proc. IEEE 3D System Integration Conference 2016, p.1-4.

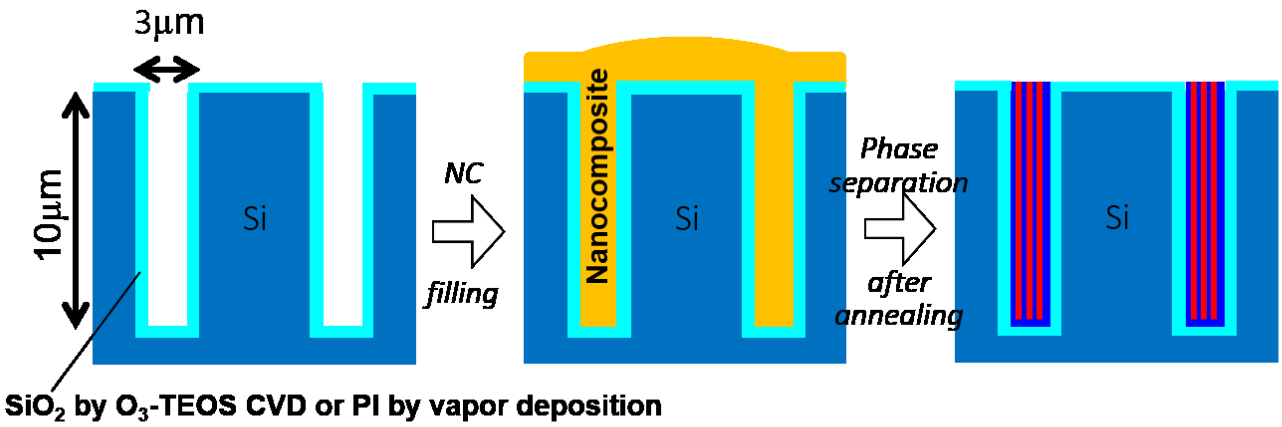

Fig. 1: Schematic process flow diagram for formation of NCs via DSA reaction inside the Si deep trenches.

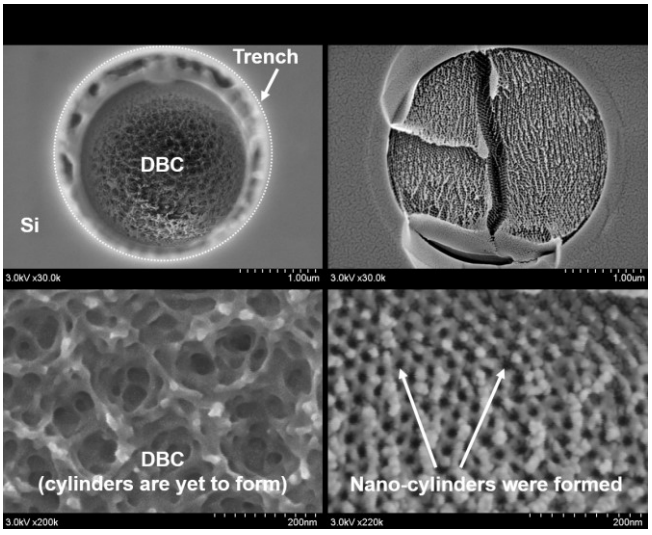

Fig. 2: Plane-view SEM images obtained before and after the DSA of PS-b-PMMA DBCs with MW 57k inside Si trench.

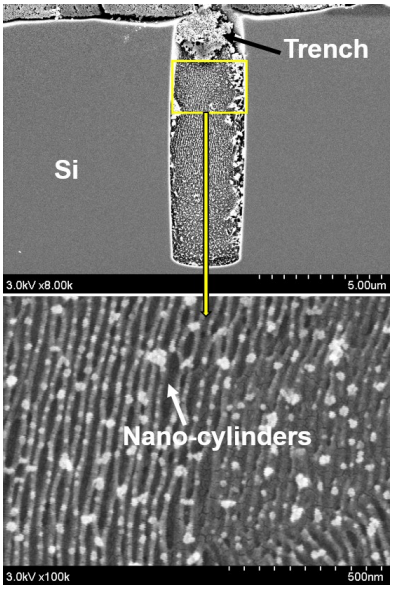

Fig. 3: X-sec. SEM images of Si deep trench filled with PS-b-PMMA DBCs with 57k as MW.

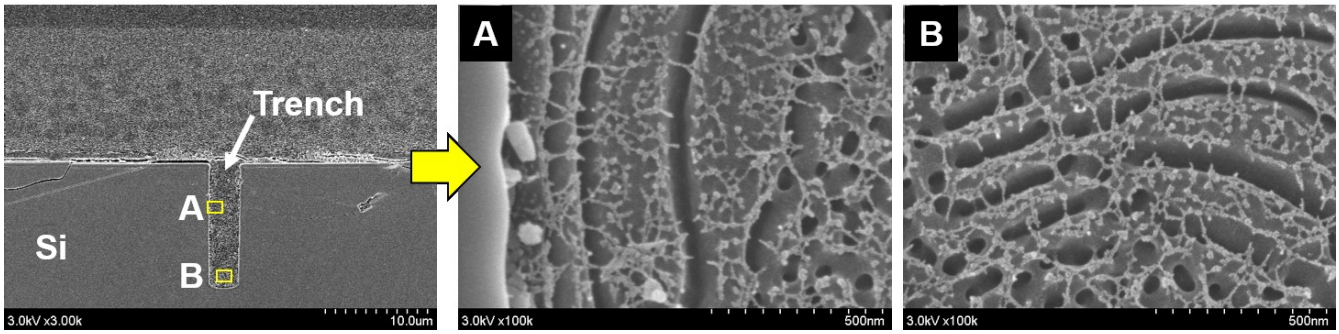

Fig. 4: X-sec. SEM images of PS-b-PMMA DBCs in Si deep trenches after DSA. It is evident that the higher the MW the larger the width of NC.