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Ultrafine Pitch TSV Technology Using Directed Self-Assembly for 3D Storage Memory Systems

T. Fukushima, M. Murugesan, H. Hashimoto, S. Lee, J. Bea, and M. Koyanagi

New Industry Creation Hatchery Center (NICHe), Tohoku University
6-6-10, Aza-Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan
Phone: +81-22-795-6906, E-mail: fukushima@bmi.niche.tohoku.ac.jp

Abstract

A DSA (Directed Self-Assembly) technology is applied to fabricate ultrafine pitch TSV (Through-Si Vias) for ultra-high density 3D storage memory systems. A nanocomposite consisting of an A-B block copolymer and novel metal nanoparticles shows nano-cylinder structures on Si substrates based on a Flory-Huggins theory.

1. Introduction

Massive memory capacities are indispensable toward upcoming IoE (Internet of Everything) with AI (Artificial intelligence). In such a next-generation society, edge computing is mainly used for real-time/high-speed communication between a huge cloud computer and terminatory electronic devices. In order to meet the demands, Intelligent Information atmosphere we call "**I**nfo-Sphere" requires an ultra-high density storage memory system that is a new NAND flash memory three-dimensionally stacked on an MCU (Memory Control Unit) as shown in Fig. 1. The memory capacity of the 3D stacked system is more than an order of magnitude higher than conventional SSD. The first 3D memory system with TSV was developed nearly 30 years ago [1]. The biggest advantage of 3D integration is that the layered structure like human brain is suitable for massively parallel processing that can not only reduce crock frequency but also enhance performance and energy efficiency [2].

DSA is well-known to be a promising lithography technology beyond EUV (Extreme UltraViolet). In a typical DSA process, an A-B block copolymer alternative to photoresists is guided by SiO_2 fine patterns to configurate ultrafine patterns as shown in Fig. 2. However, metallization processes need additional steps such as CVD, RIE, and ashing. In this work, we demonstrate for the first time to directly fabricate ultrafine pitch TSV interconnects by advanced DSA with an A-B block copolymer including metal nanoparticles. The **I**nfo-Sphere-compatible 3D integration methodology with the ultrafine pitch TSV is based on a via-last/backside via technology [3]. The target of this work is to boost the TSV density from >1K (HBM: High-Bandwidth Memory) to > 1M with ultrafine pitch TSV by advanced DSA.

2. Experimental

As shown in Fig. 3, PS-b-PMMA with the PS:PMMA ratio of 1:1 and 2:1 was employed. Si deep holes were formed with 12-inch Si wafers by Bosch etch. The diameter was 3 μm and the depth was 10 μm. Subsequently, a TSV liner dielectric SiO_2 was conformably formed in the Si deep holes by O_3-TEOS CVD at 350˚C. After that, a PS-b-PMMA solution with/without Au nanoparticles modified with a polymer was spin-coated on the deep Si holes, and then, the coupons were heated at 280˚C for 1 h *in vacuo*. After cooling, the top surface and the cross-section were observed with SEM. We used JOCTA (http://www.j-octa.com) for the simulation with support by JSOL Corporation.

3. Results and Discussion

DSA with PS-b-PMMA in deep Si holes

From the SEM images in Fig. 4, PS-b-PMMA with the PS:PMMA ratio of 1:1 and 2:1 exhibits lamella and cylinder nanostructures, respectively. Surprisingly, the nanostructures perfectly follow the curved profiles of the SiO_2 sidewall in the deep Si holes, which means the 3D nanostructures are vertically running from the TSV top to the bottom. The lamella and cylinder pitches are 20 and 40 nm. The pitches can be enlarged by the molecular weight of the block copolymers.

SCF (Self-Consistent Field) theory simulation

Phase separation from PS-b-PMMA/metal is estimated by using the mean field approximation based on SCF theory. By optimizing Flory-Huggins χ parameters and metal content, metal nanostructures are confined by PMMA cylinders in PS, as shown in Fig. 5 (a). It was confirmed that the ultrafine pitch TSV can be formed by advanced DSA. When we use 10 vol% metal as a third component in the PS-b-PMMA system, the metal nano-cylinders are turned out to be temporarily kept when the metal component can be incorporated into the PMMA domains as seen from Fig. 5 (b).

Advanced DSA with PS-b-PMMA/metal nano particles

The PS-b-PMMA with the molecular weights of 57,000 for PS and 25,000 for PMMA is soluble with the Au nanoparticles. The Au nanoparticles are covered with a polymer that has high compatibility to PMMA and high immiscibility to PS. The molecular weight is around 10,000. The diameter of the Au nanoparticles is ranging from 2 nm to 7 nm from TEM analyses. The Au/polymer composition is found to be 6.6/1 (molar ratio). The nanocomposite can be fully fulfilled into the deep Si holes. After phase separation, nano-cylinders are successfully observed on the SiO_2 surface as shown in the SEM of Fig. 6. The dimeter/pitch of the Au nano-cylinders is approximately 20/50 nm. The metal nano cylinders would be connected from the top to bottom of the deep Si holes.

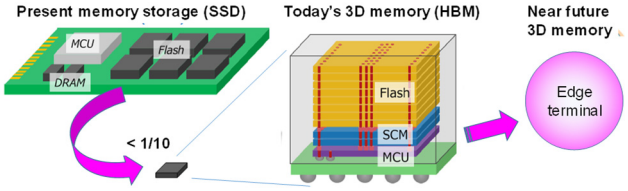

Fig. 1 A new concept of ultra-high density 3D storage memory system with ultrafine pitch TSVs for edge computing.

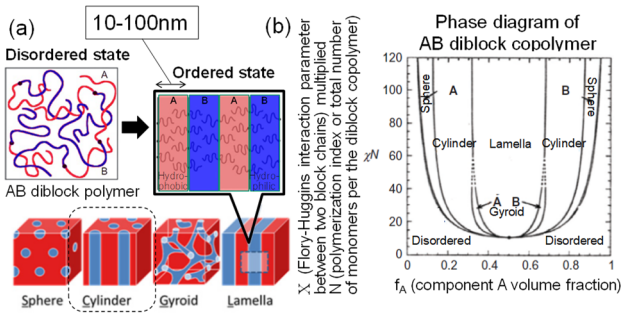

Fig. 2 Schematic illustration of typical nano-domain morphologies from an A–B block copolymer (a) and the block copolymer phase diagram (b).

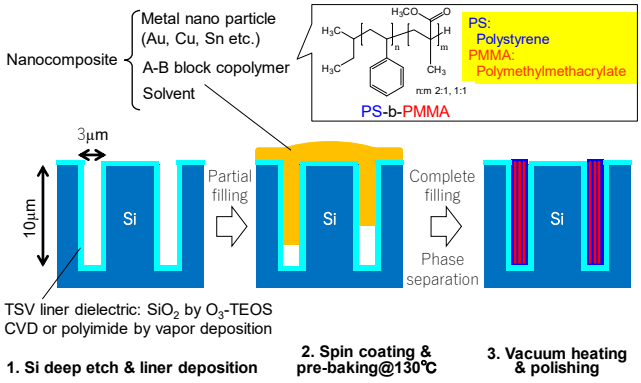

Fig. 3 A process flow for ultrafine pitch TSV formation based on DSA with nanocomposites consisting of metal nanoparticles and an A-B block copolymer.

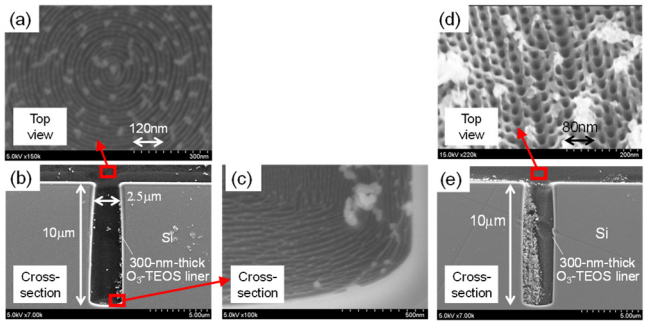

Fig. 4 SEM images of lamella (multiple annular) structure of PS-b-PMMA (1:1) in deep Si holes heated at 280˚C. Molecular weights of the PS/PMMA were 15,000/15,000 (a)-(c). SEM images of cylinder structure of PS-b-PMMA (2:1) in deep Si holes. Molecular weights of the PS and PMMA were 57,000 and 25,000 (d)-(e).

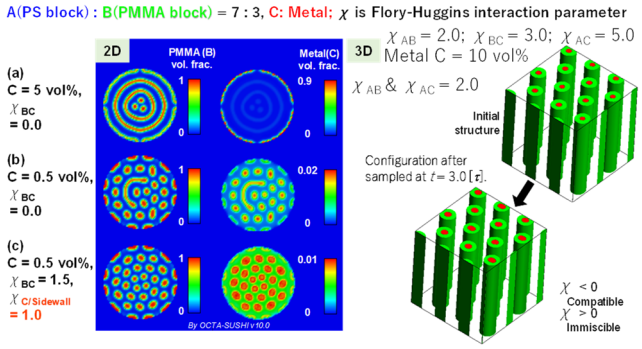

Fig. 5 2D (left) and 3D (right) morphology of PS-b-PMMA with metal in a deep Si hole calculated by the SCF theory.

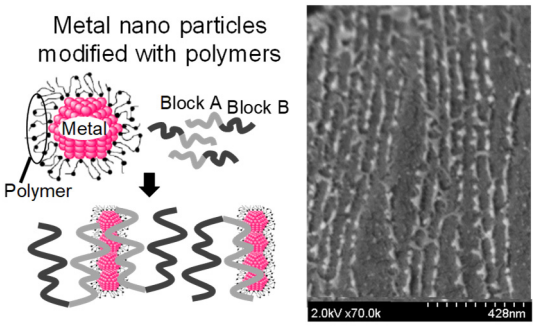

Fig. 6 Metal nano-cylinders resulted from a nanocomposite consisting of Au nanoparticles modified with a polymer.

4. Conclusions

We have successfully formed nano-cylindrical structures with PS-b-PMMA 2:1 and lamella (multiple annular) structures with PS-b-PMMA 1:1 in Si deep holes. From SCF theory simulation, if metal particles are highly compatible with PMMA, the metals are kept to be distributed into cylindrical PMMAs and vertically connected. By adding the polymer-modified Au nanoparticles into the PS-b-PMMA 2:1, 50-nm-pitch Au nano-cylindrical structures are well configurated in the deep Si holes with SiO_2 sidewall.

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