Planarization of Deep Structures Using Self-Leveling Materials

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Abstract

To achieve device integration that will allow the manufacture of smaller, more functional, and more efficient microelectronics, the industry increasingly requires materials to fill and planarize devices with deep structures. Brewer Science has developed several new self-leveling materials to address these planarization needs. These newly developed materials are designed to be either temporary materials that can be removed after their use in processing steps or permanent materials that can stay in a device for its lifetime. These new materials can be applied easily by means of a spin-coating process. They are unique because they can fill and planarize high-aspect-ratio trenches and vias hundreds of microns deep. Some of the materials are photosensitive and can be patterned using photolithography. All of the photosensitive materials in this paper can be developed with industry-accepted solvents and some with an aqueous TMAH solution. Because of their good thermal stability, high transparency, and excellent planarization properties, these materials have potential applications for microelectromechanical systems (MEMS), 3-D integrated circuits, light-emitting diodes (LEDs), semiconductors, flat-panel displays, and related microelectronic and optoelectronic devices. This paper will discuss the properties of these new materials and will present the filling and leveling results obtained in several applications.

Key words: Planarization, self-leveling, deep structures, photosensitive

Introduction

Deep structures with high aspect ratios are created during the manufacture of microelectromechanical systems (MEMS), 3-D integrated circuits, light-emitting diodes (LEDs), semiconductors, flat-panel displays, and related microelectronic and optoelectronic devices. Structures such as trenches and vias can be up to hundreds of microns deep and must be filled to provide a planar surface for further processing or to support the delicate structures from damage during processing [1-3].

Currently, one common method of planarizing deep structures is to apply an ultrathick photoresist, which often requires multiple coatings. However, photoresists have limitations in deep-structure filling and planarization. Typical issues associated with photoresists include a) air trapped in deep structures, b) an inability to completely planarize high-aspect-ratio topography, and c) undesirable overburden on top of device features [2,4].

Two processing techniques that are used for filling deep structures such as vias and trenches are spray coating and spin coating [4]. Spray coating usually involves the use of low-solids, low-viscosity coating materials. This technique requires multiple passes and may produce defects resulting from air entrapment between passes [2,4]. Spin coating often traps air in deep structures and seldom results in a defect-free and planar surface if the applied materials are not properly designed [2,4,5].

New self-leveling materials have been developed to address these planarization needs. These materials are spin coated and can be applied with existing spin-coating and lithography tool sets. They are designed to be either temporary materials that can be removed after their use in processing steps or permanent materials that can stay in a device for its lifetime. Some of the materials are photosensitive and can be patterned using photolithography and developed with industry-accepted solvents or an aqueous TMAH solution. Planarization materials with photosensitivity make it possible to use one material as both the planarization material and image-generating material. This dual functionality can greatly reduce the number of processing steps required, resulting in decreased production costs and increased yield. This paper discusses the properties of these new materials and presents the filling and leveling results obtained in several applications.

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Materials

Temporary Planarization Materials

Temporary planarization materials can fill deep structures and planarize surfaces for further processing, and the materials can be easily removed after their use. Material A is a new temporary filling material designed by Brewer Science. It has a high solids content (~50wt%) to limit shrinkage and low solution and melt viscosities to provide good filling and self-leveling properties. The low solution viscosity makes it possible for the material to fill deep structures, and the low melt viscosity of the material allows it to re-flow at elevated temperature to realize self-leveling. The melt viscosity of Material A is less than 100 Pa·s at 100°C. Also, its glass transition temperature is lower than room temperature, which allows air and residual solvent to escape easily to reduce the voids and air bubbles trapped in the film.

Figure 1 shows an example of the application of Material A. Figure 1a shows the structure before

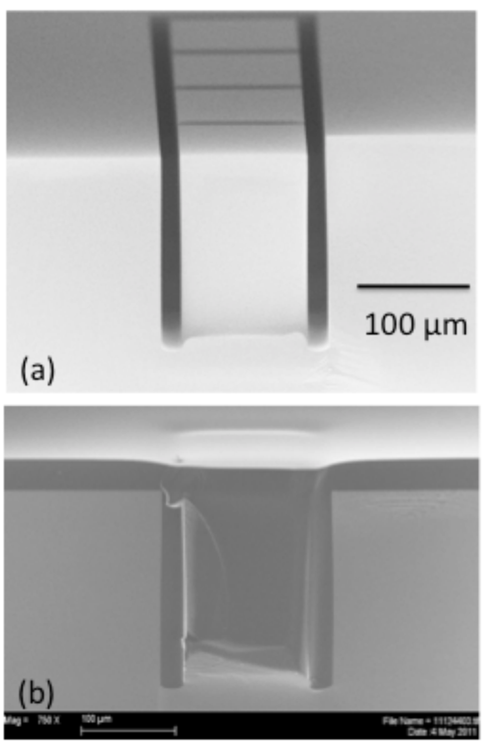

Figure 1. (a) SEM image of structure before coating. The trench is 200 µm deep with posts in it. (b) SEM image of structure filled with Material A (35wt%) by a double-coating process.

coating. It is a 200-µm-deep trench with posts in it. Figure 1b shows an SEM image of the structure after it was coated with Material A. For this application, Material A was diluted to 35wt% to achieve a better filling result. A double-coating process was used to fill the 200-µm trench. After coating, the structure was filled very well to enable further processing.

Figure 2 shows another example of using Material A to fill and planarize deep trenches. These trenches are 300 µm deep and 100 µm wide (Figure 2a). After double coating and baking, Material A not only filled the trenches, it also planarized the surface well for further processing.

Material A is soluble in common industrial solvents such as propylene glycol monomethyl ether (PGME) and propylene glycol monomethyl ether acetate (PGMEA), which makes it compatible with existing tools and processes. It is also soluble in positive photoresist developer to provide more process flexibility when it is used together with photoresists.

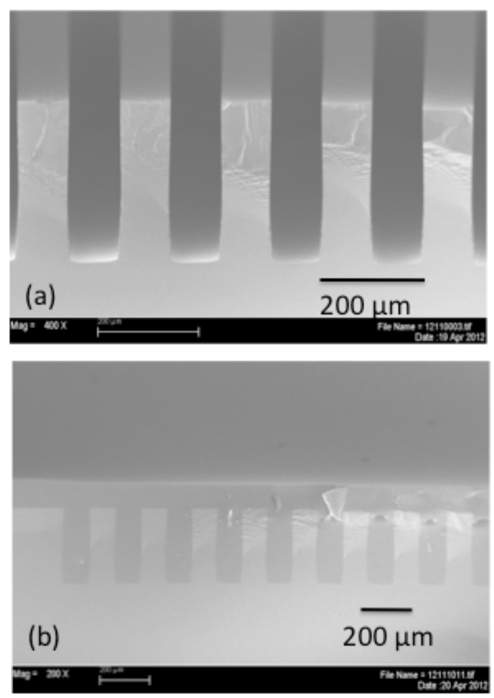

Figure 2. (a) Trenches that are 300 µm deep and 100 µm wide. (b). Trenches that are filled with Material A.

Material B is another temporary self-leveling material developed by Brewer Science. After processing, Material B can be removed by solvent. The thermal decomposition temperature of Material B in air is 290°C (as determined by thermogravimetric analysis, or TGA) which makes it suitable for use in high-temperature applications.

Figure 3 shows that Material B can fill and planarize trenches that are 6.5 µm deep and 0.6 µm wide at the top. The overburden can be reduced by using Material B with a lower solids content.

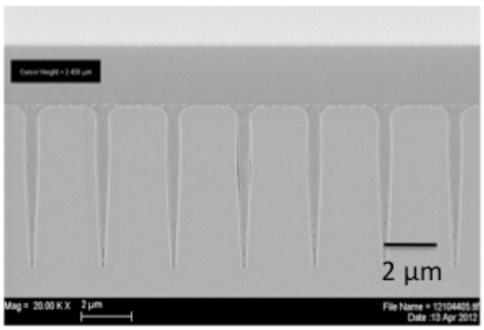

Figure 3. SEM image of trenches filled with Material B.

<u>**Permanent Planarization Materials**</u>

A permanent planarization material can stay in a device for its lifetime, but it can also be partially or completely removed by dry etching if needed.

A series of materials made with Brewer Science's Material C are permanent self-leveling materials with photosensitivity. This material series is related to Material A, so it retains the features Material A has for good filling and leveling, such as high solids content, low solution viscosity, and low melt viscosity before curing. After curing, Material C is thermally stable to temperatures greater than 250°C, compared to Material A, which is thermally stable to about 180°C. Thus, the Material C series provides a broader process window. These materials can be designed for broadband and i-line exposure and are solvent- and base-developable.

Figure 4 shows an example of filling of a deep via with a layer of Material A followed by a layer of Material C. Figure 4a shows the cross section of the via. The diameter of the via was 1 mm and the depth was ~ 300 µm. In this application, the via was first filled with a double coating of Material A to provide good filling and a planar surface. Then the via was further coated with a single coating of Material C. After exposure and post-exposure baking, Material C was cured to provide good chemical resistance and better anti-scratching functionality for further processing. Figure 4b shows that after this processing, the entire via was well filled without voids, and the surface was very planar.

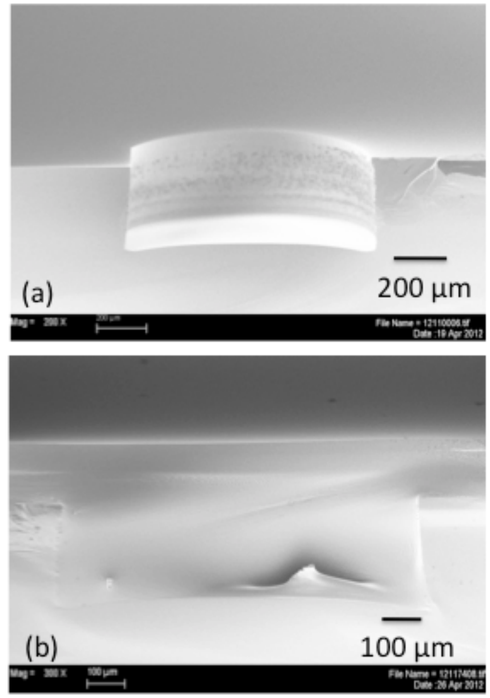

Figure 4. (a) A single via with a diameter of 1 mm and a depth of ~ 300 µm. (b) The via was filled first with Material A and then with Material C.

Permanent planarization materials with photosensitivity make it possible to use one material for planarization and image transfer. Such materials greatly reduce the number of process steps required and can thereby substantially reduce production costs and increase device yield.

Brewer Science has also developed 100%-solids planarization materials. These materials have very low viscosity, which enables them to fill deep structures easily. Because there is no solvent in these materials (in some formulations, a very small amount of solvent may be introduced from the additives), a highly planar surface can be obtained after spin coating and baking. The low viscosity of these materials also allows them to reflow at moderate temperature before curing and to generate a flat surface.

Material D is a negative-tone photosensitive 100%-solids material. After curing, it is stable to 280°C. Material D fills deep features and also planarizes the wafer surface. Figure 5a is a magnified image of a surface with small cubes on it. The cubes were uniformly covered and planarized by spin coating and then curing a 14.5-µm film of Material D on the substrate.

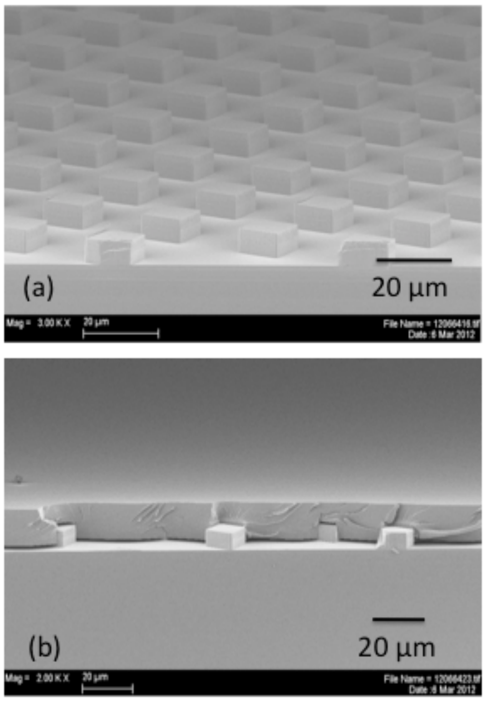

Figure 5. (a) Structure with cubes on surface. (b) The surface covered by Material D.

Brewer Science® Level™ M10 coating is a commercially available high-solids low-viscosity self-leveling material. It is a negative-tone photosensitive material. Once exposed and fully cured, the Level™ M10 coating is thermally stable up to 290°C. Level™ M10 material not only can fill deep structures, it also can fill and planarize wide structures. Figure 6a shows a typical structure to be filled with Level™ M10 coating. These trenches are 6.5 µm deep and 100-300 µm wide. After applying the Level™ M10 material, the trench was completely filled and planarized very well. As shown in Figure 6b, the total thickness variation within the 300-µm trench was less than 1 µm, and the overburden on top of the surface (5 µm away from the trench) was only 0.86 µm. An O_2 dry-etch process could be used to remove the overburden if needed.

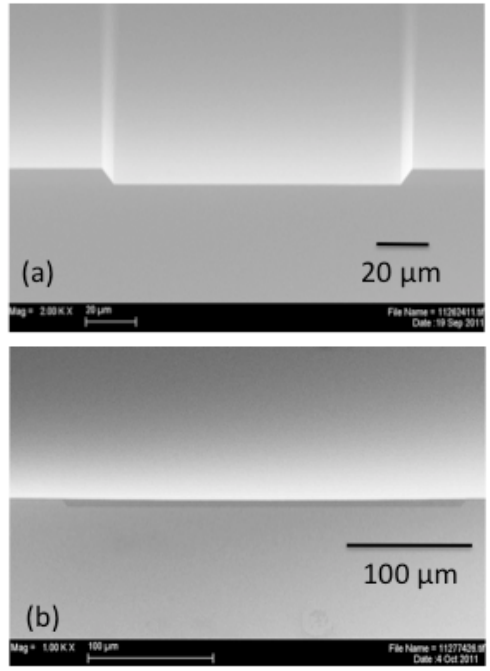

Figure 6. (a) A trench structure that is 6.5 µm deep. (b) 300-µm-wide trench filled with Level™ M10 material.

All of the materials discussed in this paper have excellent light transparency. For a 1-µm film, %T of Level™ M10 coating for wavelengths of 400-800 nm is greater than 95%, and for Materials A, B, C, and D, %T is greater than 99%.

Conclusions

Brewer Science has developed several self-leveling planarization materials for both temporary and permanent applications to meet industrial needs. All the materials are spin-on materials and can be applied with existing spin-coating and lithography tool sets. These materials have good thermal stability, high transparency, and excellent planarization properties to fill and planarize deep and wide structures. Some materials are photosensitive and developable with industry-acceptable solvents or standard developer. Self-leveling planarization materials can make significant contributions in the MEMS and microelectronic industries to enhance the performance of MEMS and other electronic devices and to reduce manufacturing costs.

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