A Study on Novel Conditioning Method for CMP Pad

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INTODUCTION

Chemical Mechanical Planarization (CMP) is an essential process in semiconductor manufacturing, and its importance has been emphasized with the design rule shrinking and increasing number of stacks used in semiconductor devices [1].

In particular, CMP Pad, one of the most important consumable materials, plays a key role in affecting whole the CMP performance because it contacts directly with the wafer in the process of polishing. Therefore, the roughness of the CMP pad surface and how to properly recover from the deformation during the CMP process are crucial. Until now, the performance has been maintained by wearing down the CMP pad with diamond disk [2][3][4][5]. This method has been working effectively so far, and thus has been adopted for most CMP processes. However, since it wears down the pad, the pad debris are generated from pad during the CMP process resulting in shortening the pad lifetime.

In this study, we have attempted to introduce a new method for pad surface recovery. What we found is we can maintain the pad surface by using a shape memory trait of pad that recovers its shape with heat and we have also successfully designed a system that can generate heat for the pad during the CMP process.

BACKGROUND

Polyurethane-based CMP pads are now widely used in semiconductor manufacturing processes. And polyurethane is used in many fields as well as CMP pad, and a lot of studies have been conducted to optimize various properties for long time. The shape memory technology is one of these efforts[6][7]. In the case of shape-memory polyurethane, research has been focused on controlling the molecular structure to improve the ability to fix after deformation and to recover when a specific stimulus (mainly heat) is applied. Since the main purpose of this CMP pad research is to restore and refresh the deformed surface to its original shape, we tried to apply recovery principle into CMP technology.

For the characteristics of deformation and recovery, it must have two molecular structural characteristics. First, there must be a soft molecular structure that can be deformed by an external force and have the power to recover to its original shape in response to a specific stimulus (mainly heat). Second, it must have a rigid molecular structure that is not easily deformed by external forces and can serve as a fixed point. The image below, Fig 1 is a schematic diagram of the molecular structure holding shape memory property. The soft segment is mainly composed of aliphatic polyether type polyols with molecular weights of hundreds to several thousands and has a relatively lower glass transition temperature (Tg) in the molecular structure. Therefore, at a room temperature, it can be easily deformed by an external force, and at a temperature above Tg, the molecules have the power to move themselves. Thus, above this temperature, the molecules can be rearranged into the most stable structure. The hard segment is mainly composed of aromatic isocyanate, low molecular weight chain extender, urethane and urea groups formed by reaction. Therefore, it has good cohesion and high Tg in the molecular structure, which makes it resistible to deformation. These traits serve as a fixing point when recovering its shape. In short, Polyurethane with this type of molecular structure can be deformed by an external force and have the characteristic of being restored to its original shape at a temperature above the soft segment Tg.

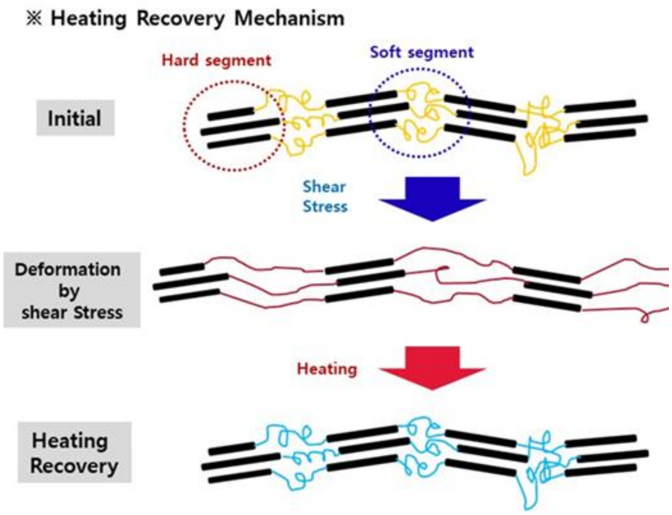

Figure 1. The scheme of molecular structure for shape memory PU and heating recovery mechanism

EXPERIMENTAL

Polyurethane resin was synthesized with shape memory properties to apply this new conditioning technology. Toluene diisocyanate (TDI), methylene diphenyl diisocyanate (MDI) and MOCA (4,4'-Methylenebis(2-chloroaniline)) were used for making the hard segment and polytetramethylene ether glycol (PTMEG) having 1,000 molecular weight was also used as raw material for soft segment. The manufacturing of the CMP pad with shape memory characteristics was carried out through the following four steps.

In the first step, we synthesized a liquid prepolymer using the above raw materials except MOCA. Next, to make a porous solid polymer, we uniformly mixed the prepolymer, foaming agent, and curing agent (MOCA) and then sufficiently cured. In the third step, to make thin sheets for CMP pad, the solid polymer was processed appropriately. In addition, we also prepared test specimens to check the thermal recovery characteristics. In the last step, to obtain a final CMP pad, we laminated it with a cushion layer and adhesive layers.

Using the specimen prepared in step 3, we have confirmed the thermal recovery characteristics as shown in Figure 2 below. Deformed surfaces were fabricated through actual CMP process, and the surface was restored by two different conditioning methods using a diamond disk and heat. And then, the pad surface conditions were analyzed by using scanning electron microscope (SEM).

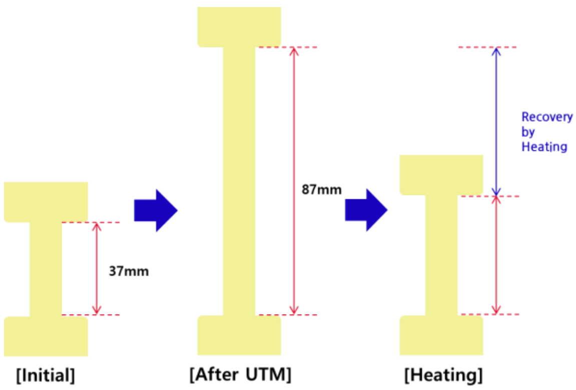

Figure 2. Test method for estimating heat recovery charactoristics

DISCUSSION

Table 1 shows the basic properties of the fabricated CMP pad. It was confirmed that the hardness was similar to that of widely used the hard-type pad in 55~60D.

Table 1. Physical properties of the test pad and conventional pad

Pad	Hardness (Shore D)	Density	Tensile strength	Elongation
Test pad	58.4	0.783	21	100
Conventional pad	56.7	0.780	20	90

Figure 3 shows the evaluation results of shape memory characteristics using heat. As you can see in Figure 3, the results show that the higher the recovery temperature and the longer time to give heat energy, the better the recovery performance. In order to effectively perform CMP pad conditioning with shape memory characteristics, sufficient thermal energy was essential to restore the pad surface. This result leads to the conclusion that in the case of a soft pad with a lower Tg, thermal recovery is possible with less thermal energy. This means that this new conditioning method is also applicable to softer pads in milder conditions.

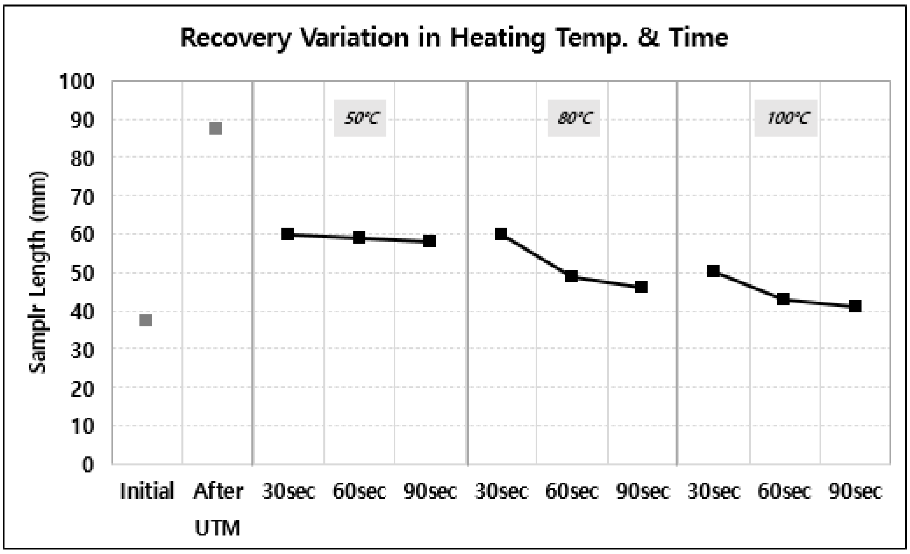

Figure 3. The evaluation results of shape memory characteristics as temperature and time

Figure 4 shows three results relatively; the surface deformed by the actual CMP process, the pad surface conditioned with a typical diamond disk, and the pad surface recovered by heat without physical external force. Figure 4 (a) shows the glazed surface without any conditioning. Figure 4 (b) shows the surface conditioned with diamond disk showing excellent openness of pores on the pad surface. Lastly, the case of 4 (c) confirms the conclusion that the glazed surface disappeared with the surface restored by heat. As it shows, since there was no wear, the initial surface shape of the pad is maintained as it was.

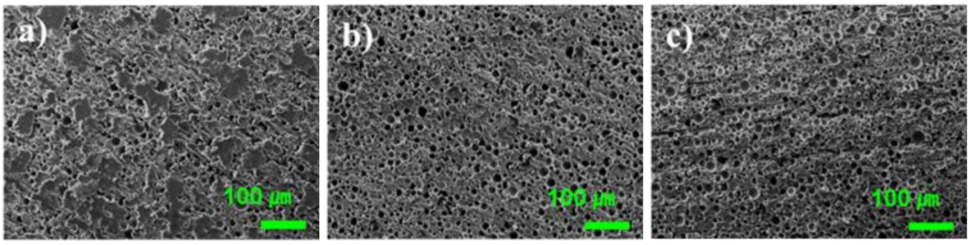

Fig 4. SEM images (x100) of CMP Pad surfaces (a) without conditioning, (b) with diamond disk conditioning (c) with heat conditioning

CONCLUSION

Through this experiment, it has been confirmed that the deformed surface during the CMP process can be refreshed by a new conditioning method using heat rather than a method that applies a physical external force to wearing it. Even if it is relatively vulnerable to decontamination that occurs during CMP, we have also confirmed that this new conditioning method that has the advantage of not generating pad debris and extending the lifetime can be optimized in combination with the diamond disk method or brush method, which removes contamination. All in all, the new conditioning method that we have successfully conducted will have a positive effect on maintaining stable CMP performance, extending pad lifetime, and reducing scratches.

REFERENCSE

[1] Hong, S., Lim, J., Kang, H., Jin, G., Kim, B., Lee, and Kim, Y., 2017, " Cu Barrier Metal Slurry for Reducing Defect-Level and Enhancing Removal Performances", Planarization/CMP Technology(ICPT), 2017 International Conference on IEEE, p1.24

[2] Aniruddh J. Khanna, Veera Raghava Kakireddy, Jason Fung, Mayu Yamamura, Puneet Jawali, Ashwin Chockalingam, Nandan Baradanahalli Kenchappa, Daniel Redfield and Rajeev Bajaj ECS J. Solid State Sci. Technol. 9 104003 (2020)

[3] Zhan L, John McCormick and Todd B, 2015, "Conditioner Characterization and Implementation for Impacts of Diamonds on CMP Pad Texture and Performance", International Planarization/CMP Technology(ICPT), 2015 International Conference on IEEE, 15805001

[4] Takashi Fujita, "Evaluation of correlation between chemical modification state of pad and polishing rate in oxide chemical mechanical planarization", Thin Solid Films 709 (2020) 138233.

[5] Jungyu Son and Hyunseop Lee, "Contact-Area-Changeable CMP Conditioning for Enhancing Pad Lifetime", Appl. Sci. 2021, 11, 3521.

[6] Byung Kyu Kim, Sang Yup Lee, Mao Xu, "Polyurethanes Having Shape Memory Effects", POLYMER Vol. 37 No.26 (1996).

[7] Moon Kyoung Jang, Andreas Hartwig and Byung Kyu Kim, "Shape memory polyurethanes cross-linked by surface modified silica particles", J. Mater. Chem., 2009, 19, 1166-1172.

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