Future Technology Roadmap for CMP Conditioning Disk

Yongsik Moon[1], Kyoung-Kuk Kwack[2], Joohan Lee[3], Jongjae Lee[2], Youngtae Jeon[2], Juhee Lee[2], and Mark Diaz[4]
[1]CMP Disk Division, EHWA Diamond, Korea, yongsikmoon@ehwadia.co.kr
[2]Research & Development Team, CMP Disk Division, EHWA Diamond, Korea
[3]CVD CMP Disk Team, EHWA Diamond, Korea
[4]General Tool, Irvine, CA, USA

Chemical Mechanical Polishing (CMP) process has been used in the semiconductor manufacturing for almost 40 years since Dr. Klaus Beyer at IBM first implemented ILD CMP for DRAM manufacturing in 1983. It became the process of choice for global planarization in the fabrication processes of a modern micro-device technology. CMP also became a key semiconductor process in manufacturing 3D devices such as FinFET transistor, or TSV-enabled wafer bonding technology.

CMP process is governed by many key components including equipment, consumables, and even design of devices. Among the key components, the CMP consumables (Slurry, Pad, Disk, etc.) are the ones which need tight control in product quality since many different lots, or batches of consumables can be used even within a day depending on the manufacturing volume.

CMP conditioning maintains the stable material removal rate (MRR) during polishing. In addition, CMP conditioning can ensure proper within-wafer-non-uniformity (WIWNU) throughout the entire pad lifetime. With fully optimized process condition, it can extend the usage of CMP pad for lower cost of consumables in CMP manufacturing.

CMP disks are made generally from three different type of manufacturing processes, Electroplating, Sintering/Brazing, and CVD processes. The CMP process condition and their process requirement can determine which type of disks is needed. The pros and cons of each CMP disk type are reviewed and compared. In addition, the future technology development roadmap for each type of CMP conditioning disk is addressed, Figure 1.

Technology roadmap for CMP conditioning disk can be divided into two scales: Macroscopic area and microscopic area, Figure2. Macroscopic area can cover the controllability of active diamond which engage with polishing pad surface by providing parallelism between pad and diamond grits on the disk surface. The key technological development needs to happen in microscopic area. First, the bonding force between diamond and metal matrix must utilize an appropriate bonding technology for each CMP conditioning disk. Bonding mechanism between diamond and metal matrix must be fully understood for each application to reduce or eliminate the potential of “diamond loss” during CMP manufacturing process causing excursion in HVM semiconductor manufacturing.

Filtering bad diamonds is always a challenge for many CMP conditioning disk suppliers. A single bad diamond embedded on the CMP disk coming out during CMP, can cause a devastating manufacturing excursion in a HVM semiconductor device company. Artificial intelligence including deep learning technology is used to ensure accurate classification between good diamonds and bad diamonds on the CMP disk during diamond inspection step, Figure 3. Convolutional neural network is typically used to ensure accurate classification for defect diamond.

Diamond shape and size plays a major role in controlling aggressiveness of pad conditioning and pad cut rate (PCR) during the CMP process. CMP conditioning is similar to metal cutting process in mechanical engineering, Figure4. The smaller rake angle, the higher the metal cutting power is in metal cutting process. Diamond dihedral angle in a diamond on a CMP conditioning disk performs like rake angle in metal cutting. The smaller dihedral angle of diamond like Octahedral diamond can generate higher PCR than that of smaller dihedral angle of diamond like of Cubo-Octahedral, or blocky diamond at CMP diamond disk. Pad cut rate is often correlated to the surface roughness of pad surface. In general, higher pad surface roughness generates higher MRR since higher pad surface roughness can provide more pad-wafer surface contact area and, thus, higher MRR.

As we move to more advanced technology nodes, CMP will be tasked to remove various materials such as SiC, GaN, Mo, or Ru, etc. Higher acidic or alkaline slurries are being used in advanced metal CMP processes and conditioning disk should be able to perform well under any CMP slurry conditions.

In the advanced W CMP slurry (pH 1~2), ferric nitrate ($Fe(NO_3)_3$) oxidizer is used as a stronger oxidizer to promote higher W MRR. Fe ion in the slurry can wear out diamond faster than any other slurry. This is the reason why in general, ex-situ conditioning is used at W CMP process. More durable diamond is needed to ensure longer pad lifetime and CMP uptime. ‘Long-Lasting Diamond (LLD)’ technology is introduced in this paper. LLD can last at least 50% longer than the regular diamond disk in high acidic slurry environment. LLD technology can also be applied at the high alkaline slurry with strong oxidizer like potassium permanganate ($KMnO4$) for SiC CMP. In this paper, ‘specially engineered diamond disk‘ using LLD for SiC CMP is introduced.

CVD diamond disk is one of the future technologies in CMP conditioning disk. It ensures consistent pad-diamond contact area which results in stable MRR, WIWNU, and defectivity throughout the entire pad lifetime, Figure5. One of the biggest features of a CVD disk is that it provides maximum number of active diamond tips during pad conditioning due to superior disk flatness. The contact mechanism between pad surface and diamond tips can be engineered based on the pad type to provide optimized CMP performance. No concern in chemical compatibility is another advantage in using full face CVD diamond coated disk in any metal CMP process.

In this paper, the overall future technology roadmap of each CMP conditioning disk is addressed for the future CMP process. The pros and cons of different types of CMP conditioning disks are reviewed and their future technology roadmap is discussed and suggested.

Corresponding Author:
Yongsik Moon
E-mail: yongsikmoon@ehwadia.co.kr

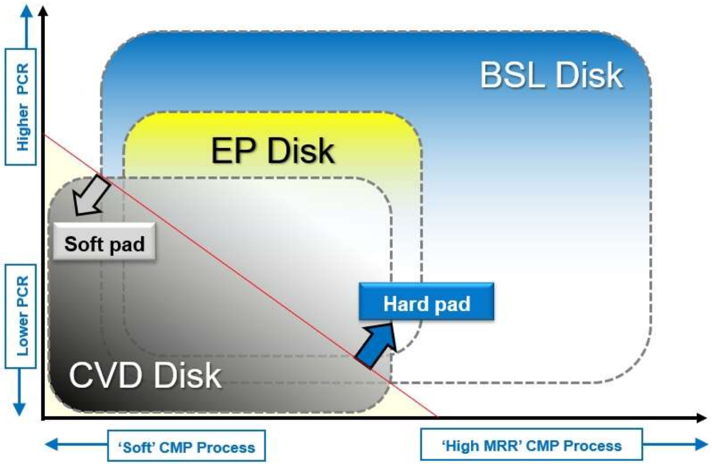


Figure 1. Three types of CMP conditioning disk

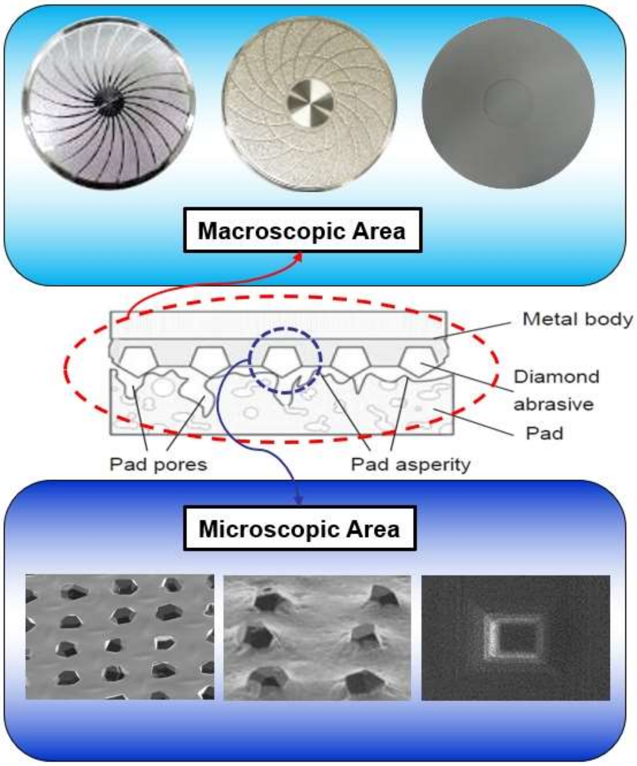


Figure 2. Macroscopic and microscopic area in disk development

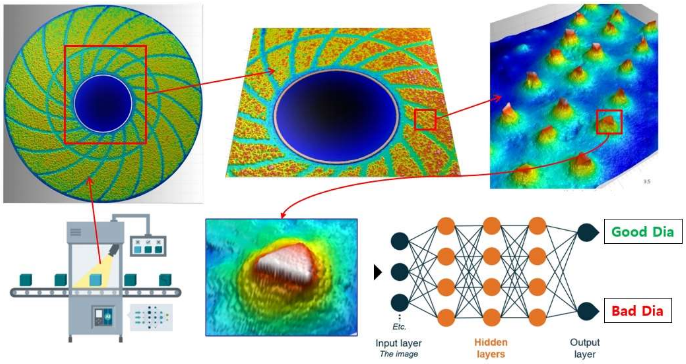
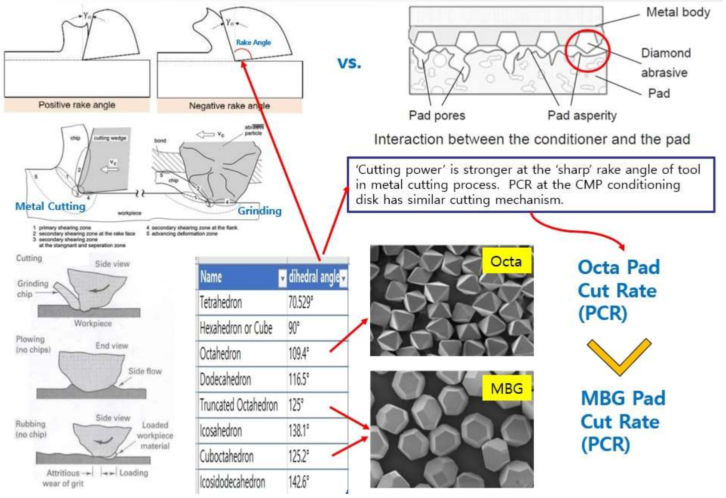


Figure 3. A.I. in diamond inspection



'Cutting power' is stronger at the 'sharp' rake angle of tool in metal cutting process. PCR at the CMP conditioning disk has similar cutting mechanism.

Name	dihedral angle
Tetrahedron	70.529°
Hexahedron or Cube	90°
Octahedron	109.4°
Dodecahedron	116.5°
Truncated Octahedron	125°
Icosahedron	138.1°
Cuboctahedron	125.2°
Icosidodecahedron	142.6°

Figure 4. PCR vs. Diamond dihedral angle

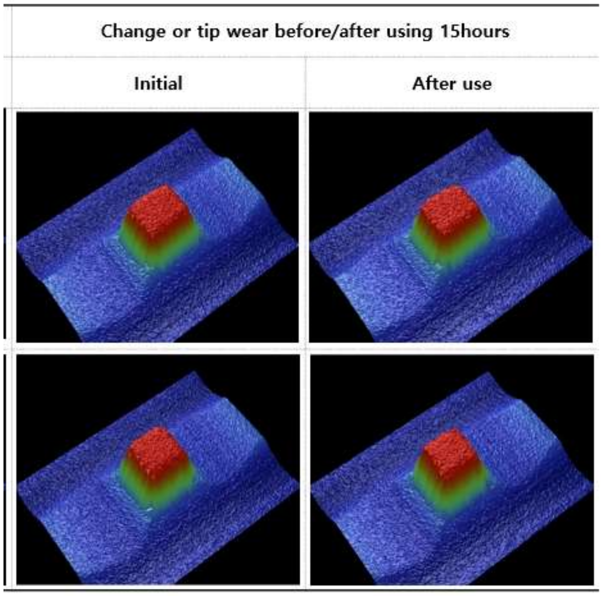


Figure 5. Area of contact at CVD diamond disk

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