Wafer Bonding Process using Atmospheric Plasma

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Abstract:
3D integration technology using wafer bonding process has been promised way to solve the limit of Moore's law. Our previous studies of surface treatment for wafer bonding using vacuum plasma showed higher bonding strength, as plasma power comes into lower range, i.e. low ion energy. Here, we investigated the feasibility of atmospheric plasma treatment with very low ion energy by extremely lowering the mean free path of the ion. Typical bonding strength of the SiCN-coated Si wafers was achieved over 2.0 J/m^2 by optimization.

Keywords: SiCN-SiCN Bonding, Wafer Bonding, Plasma Activation, Atmospheric plasma.

1. Introduction

As the semiconductor is highly scaled down, the difficulty of the scaling process increased rapidly, and the cost and development period increased. Accordingly, 3D integration of memory devices is emerging as a new technology for high integration memory. Typically, bonding technology which was widely used in CIS (CMOS Image Sensor) device manufacturing, has recently been widely applied to devices such as DRAM, NAND and CPU/GPU. YMTC has released a VNAND product that applies Xtacking^{TM} technology [1] that stacks wafer including cell array over the wafer of peripheral area with wafer bonding technology. TSMC also applied hybrid bonding technology to develop 3DFabric^{TM} technology that stacks SRAM over CCD (Core Complex Die) and applied the technology to AMD's new product. [2]

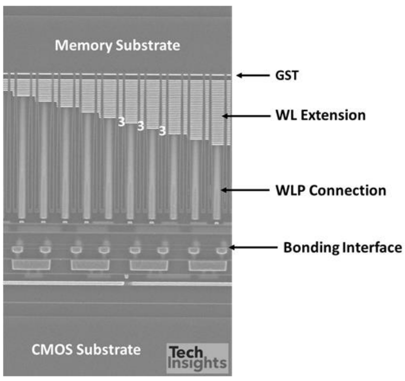

Fig. 1. Example of bonding process
(YMTC 64-layer 3D Xtracking in Nand Flash) [3]

As hybrid bonding technology is applied to DRAM and VNAND devices, the required I/O density increased rapidly. As a result, the ratio of Cu/Dielectric layer in the bonding interface increased, and the bonding strength between the dielectric layers has an important effect on the performance and reliability of the device. Various studies have been conducted in related to bonding strength in hybrid bonding, including the materials, characteristics and surface treatment process of the dielectric layer.[4]-[6] In particular, Choi, *et al.* [7] studied N_2 plasma surface treatment process for Si-SiO_2 bonding. As a result of the study, it was confirmed that the bonding strength was lowered at a specific values or higher for both source/bias power in the CCP type plasma chamber, as found in Table 1. Assuming that low power plasma means low ion energy, it is necessary to study the feasibility of the plasma process that uses the plasma treatment with very low ion energy by extremely lowering the mean free path of the ion. Therefore, this study aims to evaluate the bonding strength in the atmospheric pressure plasma process. In chapter 2, the atmospheric pressure plasma system and the experiment parameters are noted. Following chapter reports the wafer bonding process under atmospheric pressure, and the results of void and bonding strength. In addition, the optimization strategies to increase bonding strength is discussed. Chapter 4 notes the conclusion of this study and discussions on the meaning of the atmospheric pressure plasma treatment to the hybrid bonding process.

Table 1. Bonding strength measurement of SiO_2-Si bonded wafers as N_2 plasma power conditions

	Source Power [W]	Bias Power [W]	Bonding Strength [J/m^2]
1			3.58
2			3.57
3			3.62
4			3.48
5			3.48
6			3.53
7			2.19
8			2.70
9			1.46
10			1.65

2. Experiment

Figure 2 shows the top view of Ar Atmospheric plasma Schematics. The direct plasma treatment method was selected, because this is similar to CCP chamber. RF (Radio-Frequency) power similar to CCP chamber was applied, and Ar gas was applied accordingly to atmospheric plasma. RF power had ranges from 400 to 800W, and the frequency is 13.56MHz. Plasma treatment was performed as indicated in Fig 3. The gap between the reactor and the stage is 3 mm. In this experiment, a bar-type plasma reactor was used.

Accordingly, a scan speed (mm/s) to cover full wafer (300mm) surface is one of important knobs to control the plasma reaction time as well as through-put. Total treatment time was limited within several seconds.

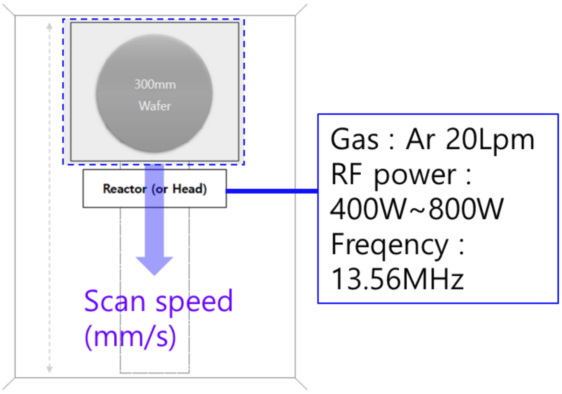

Fig. 2. Ar Atmospheric plasma Schematics

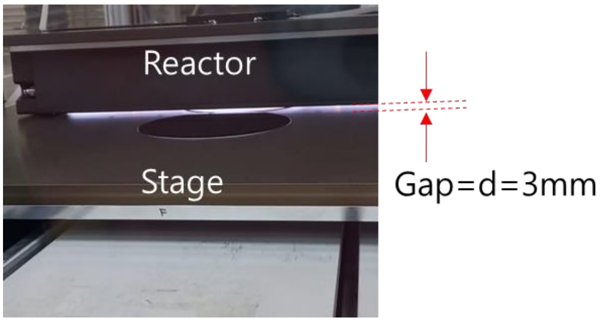

Fig. 3. Atmospheric plasma treatment side view

After activation of wafer surface by Ar-plasma in the atmospheric pressure (Fig.3), wafer was rinsed with deionized (DI) water to remove any particles and also to produce sufficient hydrophilicity. Afterwards, two wafers were put into bonding module to make mechanical alignment and brought into contact in the ambient temperature and atmosphere. Finally, the bonded wafers were annealed at 350℃ for 1 hour, followed by the bonding strength was measured using the blade insertion method described by Maszara et al. [4]

The experimental parameters can be determined as applied power, gap, Ar flow, and scan speed. However, the power was selected as the reference power with the minimum power of 400W, in order to lowering ion energy based on previous research. For the same reason, the atmospheric plasma gap is 3mm, which is the maximum gap to be evaluated, and the Ar flow satisfying those two conditions (power & gap) was selected as 20Lpm (Litter per minute). Thus, in this study, Scan speed was mainly evaluated as a main variable. Because it is a variable related to the reaction time of the plasma and wafer surfaces, and it is to find out how much time the plasma treatment is the most bonding strength.

3. Results

Before the Anneal process, full wafer was measured using SAT (Scanning Acoustic Microscopy). SAT is a non-destructive analysis equipment that can measure the size of bonds, breaks, peeling, and voids in Wafer by using the ultrasonic waves. Prior to wafer bonding, particles on the plasma treated wafers were measured using SAT. Especially particles larger than 1um create voids during bonding wave propagation, which can be one of main bonding failure reasons. Compared to our previous study using CCP in vacuum condition, particles inclusion is easily happened in case of the atmospheric plasma treatment as shown in Fig.4 (a). However, it was effectively suppressed by local partition against surrounding air-flow and particle sources (Fig.4 (b)).

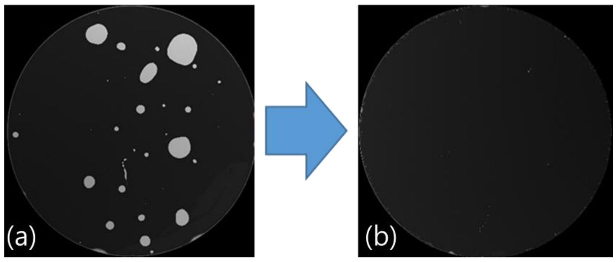

Fig. 4. SAT images: (a) Bulk voids affected by particles during bonding, and (b) Suppressed voiding by partition

SAT images of wafers processed with the scan speed of por, por*2, por*6 mm/s, respectively. As the scan speed increased, the particle decreased. (After wafer treat in the atmospheric plasma, due to manual movement, there is a void in the wafer edge)

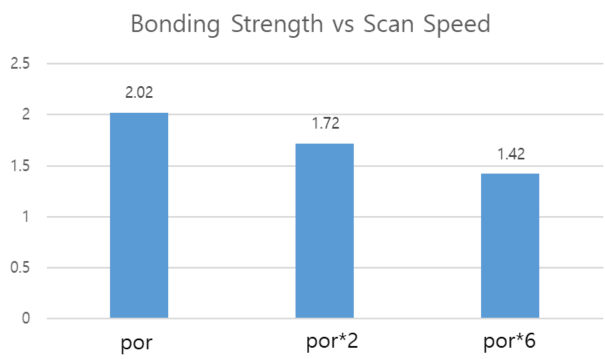

Fig. 5. Bonding Strength (J/m^2) vs. Scan Speed (abs)

Figure 5 shows the result of measuring the bonding strength (J/m^2) for each scan speed. As Scan Speed increased, bonding force tended to decrease. This causes a hydrophilic reaction on the surface, which can be affected by Scan Speed.

The influence of the previous plasma parameter and bonding force is shown in Fig 6. As mentioned in chapter1, the lower the power, the stronger the bonding strength.

The larger the plasma gap, the lower the ion energy at the same power, but the energy required for the plasma ignition tends to increase (Pascha's law). So in this sense, the smaller the gap, the better the bonding strength.

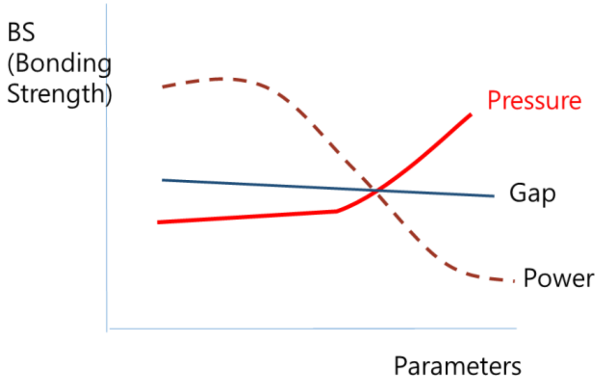

Fig. 6. Parameter vs Bonding Strength (abs)

However, when atmospheric plasma has a gap of 2mm or less, it will be worse due to plasma instability and non-uniformity. Pressure did not have a significant effect on vacuum, but it can be seen that it compensated for the decrease in ion energy as it came to atmospheric pressure.

4. Conclusion and Future Work

The plasma activation for wafer bonding was mainly carried out under vacuum conditions. In this study, plasma treatment was studied under atmospheric plasma conditions that can minimize ion energy. As a result of evaluating various conditions such as plasma power, gap, flow rate, and scan speed, it was possible to secure the feasibility of the atmospheric plasma process by checking the bonding strength of up to 2.0J/m^2 under almost void-free conditions.

In general, wafer bonder equipment is integrated with plasma modules, clean modules, and bonding modules. When atmospheric pressure plasma is adopted to plasma module, although the sophisticated particle management is required, it has the advantage to configure equipment and facilities easily because it does not require main parts such as high-performance pumps or vacuum chambers. It will provide a lot of flexible configuration with lower cost as well as higher through-put, in which resulting in a new paradigm for wafer bonding equipment technology.

5. References

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