DEVELOPMENT OF FORCE AND MOMENT CONTROL MECHANISM FOR ROTATING PARTS USING ELECTROMAGNETIC FORCE (APPLICATION OF CMP HEAD)

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1. Introduction

Semiconductor devices have achieved high performance, high function and high density with incredible speed. This trend is accelerated by introduction of CMP technology. For miniaturization and integration in semiconductor process of <90 nm node, it is indispensable to achieve Cu/low-k CMP process at low pressure of <1psi. The lower the dielectric constant (=k), the lower the mechanical strength and adhesiveness. Therefore, lower pressure polishing CMP system is necessary. Especially in case of ultra low-k material of k<2, which consists of low-density and high-porosity material, development of CMP technology at <0.1psi (690Pa) ultra low pressure is required.

However, in the CMP process with low pressure, we have to face a difficult issue: poor uniformity. To obtain as good uniformity as at high pressure polishing, a capability of removal profile control is required. Our CMP system (NPS3301) is developed by the concept of local polishing using a smaller polishing pad. The local polishing mechanism has a capability of removal profile control by changing the polishing parameters: wafer spindle speed, polishing pad spindle speed, and oscillation stroke & start position. Then Nikon CMP tool is the first successful system in the world that achieved <0.1psi (690Pa) polishing for Cu/ultra low-k films.

In mechanical polishing, the removal amount can be determined by polishing pressure, relative velocity, and polishing time (Preston's equation). In local polishing method, the removal amount is to be controlled by changing relative velocity and polishing time. To enlarge the range of polishing profile, the control of polishing pressure is required. On the current CMP mechanism, polishing pressure is generated by air pressure. Air pressure control is good for maintaining constant pressure, and it is not good for changing pressure quickly. Moreover the pneumatic mechanism for controlling the moment of rotating parts is very difficult. So we developed new mechanism using electromagnetic force. Changing the electric current, generated electrical magnet force is changed. In the case of CMP, a polishing pad is to be dressed each time after wafer polish. The pad thickness becomes thinner. Using electrical magnet force, the relation ship between force and gap is non-linear. A general mechanism needs a gap sensor and a force transducer. Our force control system uses only force transducer and achieves to have a good response enough to adapt for CMP head.

This presentation refers to the force control mechanism and the force control system newly developed. To verify the system design and concept, the basic experiment was carried out, and the results are reported.

2. Polishing System

The polishing mechanism on this system uses a smaller polishing pad than wafer as shown

in Fig.1 enabling local polishing. It is judged that the product of relative speed and polishing time is more precisely controllable than the polishing pressure on Preston's empirical formula. This system has the mechanism to control the oscillation position and the speed of polishing pad. Slurry is delivered to a wafer rotating face up from a center of polishing pad, which pushes polishing pad downward. This mechanism enables uniform chemical effect by flowing slurry over polishing area almost uniformly.

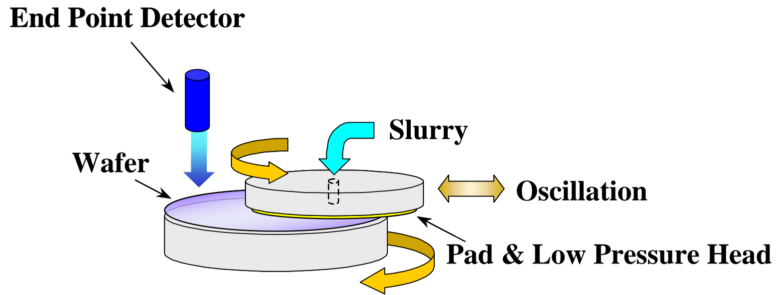


Fig.1 Polishing Mechanism

3. Development of CMP Polishing Head

3-1.Mechanizum

The mechanism is required non-contact for used in a clean room. The electromagnetic force system (CI-core) is adopted to maintain the uniform pressure on the pad/wafer contacted area. The force pulling up I-core is generated by supplying electric current to the coil attached in C-core. Controlling a rotating part, I-core is made ring-shaped and attached to the rotor. (Fig.2) C-core which needs wiring is fixed to non-rotating part. In order to control force and moment for a rotating part, the system needs three C-cores at least. Figure 3 shows the wafer polishing force distribution with the side-view plot. To obtain the uniform contact pressure on the pad/wafer contacted area, the following equations are required.

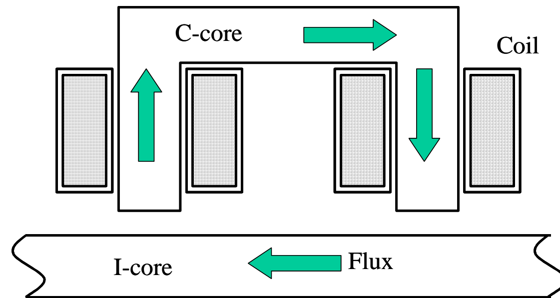
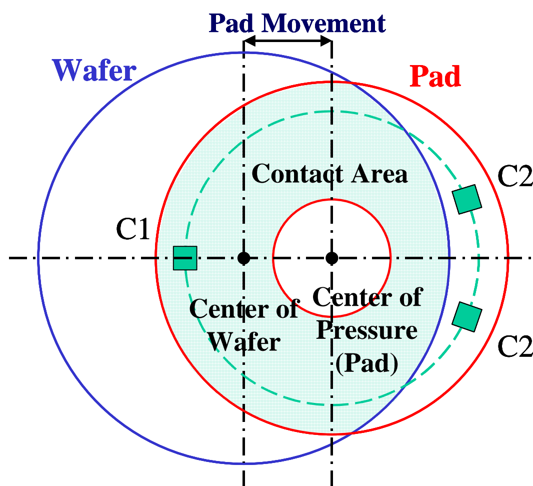


Fig.2 C-I Core



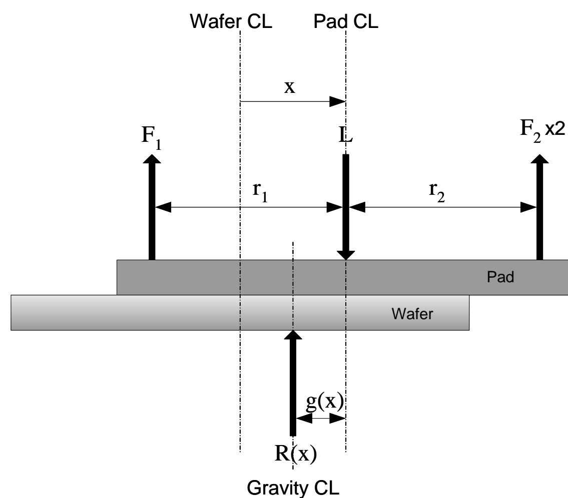


Fig.3 Wafer Polishing Force Distribution

$$F1+2*F2+R(x)=L \qquad (1)$$
$$F1*r1+R(x)*g(x)=2*F2*r2 \qquad (2)$$

Using CI-core, the relationship between a gap distance and a generated force is not non-linear in the case of constant supply current. In CMP process, the pad is dressed and its thickness is reduced after polishing a wafer every time. The reduction of pad thickness changes the gap and causes the non-linearity problem. The load cell is attached to C-core.

3-2.Controller

For a controller, two items are required mainly. One is how to calculate the output signals of three C-cores. The other is how to optimize the gain caused by the mentioned non-linear relationship. About the first item, the contact area and its gravity center distance can be calculated by geometric equations (1), (2) as the pad position is known during polishing by a rotary-encoder attached to the oscillation arm. About the non-linearity problem, the adaptive gain adjustment (AGA) servomechanism was developed. The AGA servomechanism includes the real-time force gain estimate scheme and the extra adaptive gain adjustment block in the servo loop. If the adaptive gain adjustment block has the fixed gain one, it would be the conventional feedback control system.

4. Experiment

Before assembling the developed mechanism to CMP polishing head, the basic experiment was conducted. I-core was attached to the spindle of milling machine and C-core with the load cell is fixed on the table, and the gap sensor detects the gap between cores. A result is shown in figure 4. The output of the load cell is the almost same value as the command signal. The gap signal is combined two sine waves. One is synchronized with number of rotations, and the other is synchronized with the force generated by C-core. It has checked that the force can be transmitted to a solid of revolution by non-contacting, and that the nonlinear measure in a controller had been successful.

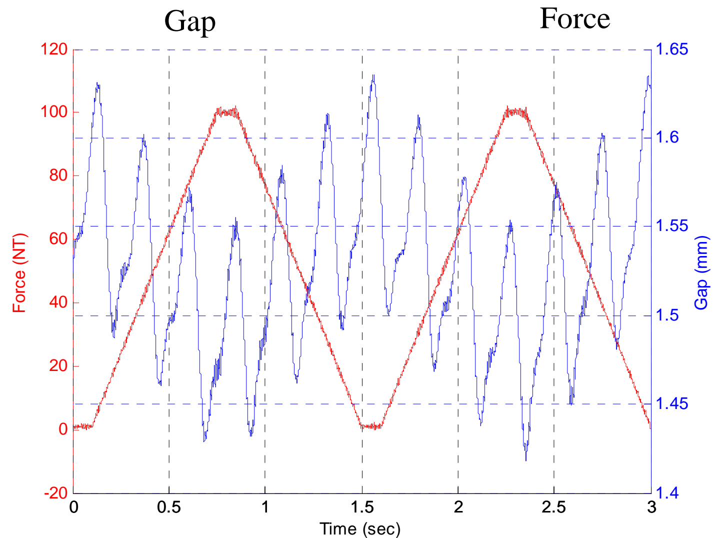


Fig.4 Force Control and Gap

After assembling the mechanism to CMP system, a pressure distribution on the wafer surface is measured by a pressure measurement sheet to investigate the moment compensation. The results show figure 5 The pressure concentration at the upper right can be decreased by C-core force controlling. Then a polishing experiment is carried out and the polishing profiles is shown in figure 6. Since the pressure concentration at the edge of wafer is decreased, the profile is changed from concave to convex. Thereby the effectivity of the developed system is confirmed.

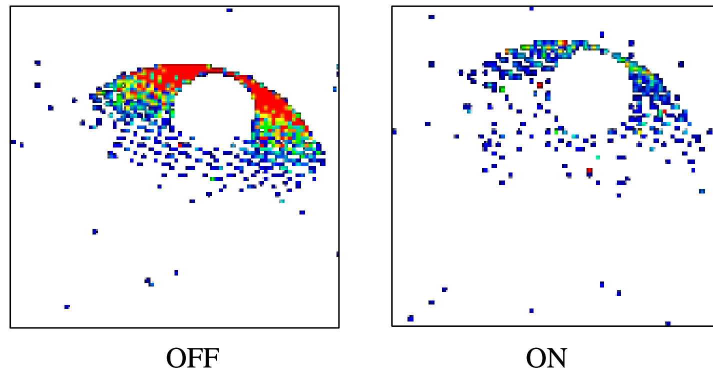


Fig.5 Pressure Distribution on Wafer Surface

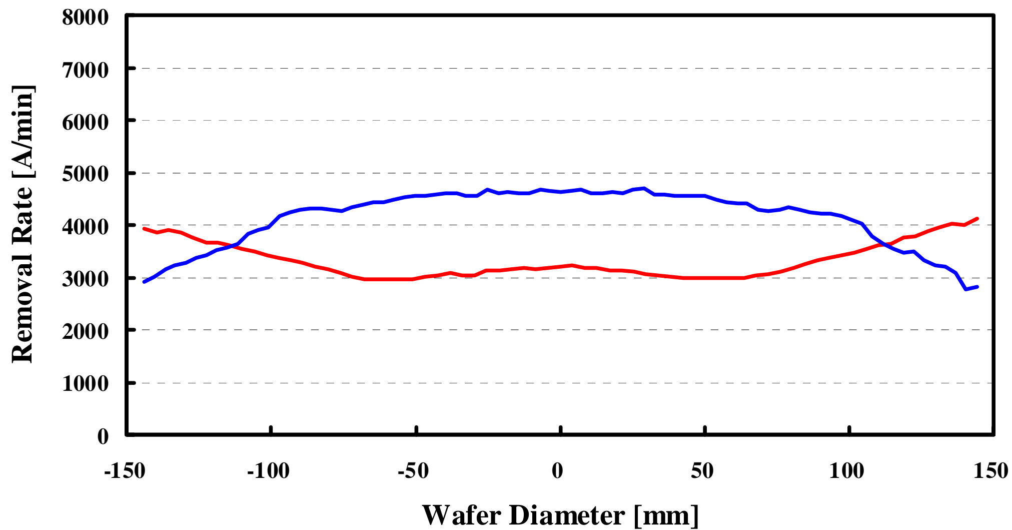


Fig.6 Polishing Profile

5. Conclusion

The force & moment control mechanism for rotating parts is developed using electromagnetic force. Then it is applied to CMP polishing head. The basic and polishing experiments are conducted and the effectivity of the developed system is confirmed. Thereby the control range of polishing profile will be able to expand

References

1. T.Doi, Details of Semiconductor CMP Technology, Kogyo Chosakai Publishing Co., Ltd. 2001
2. International Technology Roadmap for Semiconductors, 2003 Edition
3. F.W.Preston, The theory and design of plate glass polishing machines, J. Society of Glass Tech., 1972, 214-256
4. Y. Uda, T. Senga, A. Ishikawa, E. Yamamoto, T. Mitsui, S. Hoshino: Digital Polishing Method for CMP System using a Smaller Diameter Polishing Pad, ASPE on 12th, Nov.2001
5. **S. Hoshino, Y. Uda, E. Yamamoto : Characteristics of Cu CMP Process on Ultra-Low Pressure, CMP-MIC, Feb.2004**