ASIATRIB 2002International Conference
JEJU ISLAND, KOREA

Dependence of Dishing on Fluid Pressure during Chemical Mechanical Polishing

C. Fred Higgs, III, Sum Huan Ng, Chunhong Zhou, Inho Yoon, Robert Hight, Zhiping Zhou[+], LipKong Yap and Steven Danyluk

The George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA. 30332-0405

[+]Microelectronics Research Center
Georgia Institute of Technology
Atlanta, Georgia USA 30332-0269

Chemical mechanical polishing (CMP) is a manufacturing process that uses controlled wear to planarize dielectric and metallic layers on silicon wafers. CMP experiments revealed that a sub-ambient film pressure developed at the wafer/pad interface. Additionally, dishing occurs in CMP processes when the copper-in-trench lines are removed at a rate higher than the barrier layer. In order to study dishing across a stationary wafer during polishing, dishing maps were created. Since dishing is a function of the total contact pressure resulting from the applied load and the fluid pressure, the hydrodynamic pressure model was refined and used in an existing model to study copper dishing. Density maps, highlighting varying levels of dishing across the wafer face at different radial positions, were developed. This work will present the results.

Keywords: Chemical mechanical polishing, planarization, copper, dishing

INTRODUCTION

Chemical mechanical polishing (CMP) is a method used in semiconductor manufacturing to achieve global planarization on a silicon wafer. Chemical mechanical polishing (CMP) is a manufacturing process that uses controlled wear to smooth a surface with minimal surface damage [1]. While this advanced manufacturing process is suitable for very small-scale local and global planarization, much remains to be done to understand the process. In experiments, it was observed that a sub-ambient slurry pressure developed [2]. A model was developed to explain the suction pressures [3].

More recently, copper has emerged as a more favorable metal interconnect than aluminum [4]. Consequently, research centers around optimizing copper CMP. Two major problems with the planarization of copper (Cu) and dielectric materials are dishing and erosion. Currently, the focus of this work is on studying the dishing across a silicon wafer. In this paper, we present the development of dishing-on-wafer maps as a function of the contact stress and fluid pressure.

THEORY

An existing dishing model determined the average dishing as the difference between the removal rates of the barrier film and copper lines. It was reasoned from this, that the copper dishing, h_D, is described by the relationship [5]:

$$h_D = \frac{(S-1)P_{app}H}{S\,E}\xi \ln(\frac{w}{w_o})(1-e^{\frac{-K_{Cu}EU}{H}t}) \tag{1}$$

The interfacial pressure can be determined from contact stress and the local film thickness.
The pressure model agreed with experiments conducted with a steel fixture [3]. In that work, the pressure was predicted according to Reynolds' equation as a function of the contact stress σ and film thickness h as:

$$\frac{d}{dx}\left(\phi_x h^3 \frac{dp}{dx}\right) = 6\mu U \frac{dh}{dx} \tag{2}$$

where, ϕ_x = pressure flow factor.
The use of the pressure and shear flow factors (ϕ_x, ϕ_s) account for the difference in flowrate through a smooth and rough contact region [6]. Therefore, the pressure equation can be expressed as:

$$\frac{d}{dx}\left(\phi_x h^3 \frac{dp}{dx}\right) = 6\mu U \frac{dh}{dx} + 6U\,s\frac{d\phi_s}{dx} \tag{3}$$

Taking the boundary pressure values as ambient, equation (3) was solved using finite differencing in Mathematica®. The resulting contact stress on the wafer surface gives a total contact pressure P_{app}, which is the difference between the contact stress and the fluid pressure:

$$P_{app}(x) = \sigma(x) - p(x) \tag{4}$$

This total contact pressure can be used to compute the dishing as a function of position using equation (1).

RESULTS AND DISCUSSION

In Cu CMP, dishing makes the achievement of global planarity problematic. Since it is difficult to visualize how the dishing behaves across a wafer surface, dishing density maps were developed to capture the varying magnitudes. Dishing maps are helpful for understanding how it behaves at various points on the wafer during polishing. Figure 1 shows a map of the copper dishing across the 0.1m wafer.

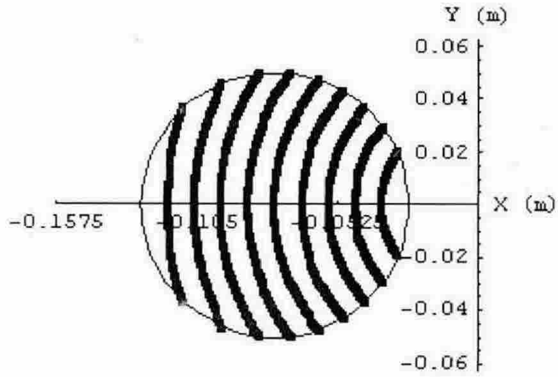

Fig. 1: The map shows dishing as a function of position.

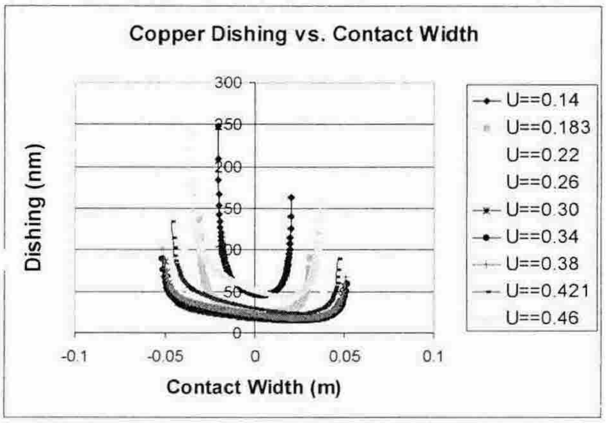

Fig. 2: Copper dishing as a function of contact width.

In Fig. 1, the higher densities of red represent higher dishing regions. In Fig. 2, the Cu dishing is shown at different velocities (i.e., pad radii) as a function of contact width using equation (1).

CONCLUSION

Existing models compute dishing as a function of contact stresses resulting from the normal load and fluid pressures. Dishing maps were developed to demonstrate the varying levels of dishing on a wafer surface. Such maps will serve as powerful tools for visualizing the effects of dishing and erosion during CMP. A new model for dishing will also be introduced in this presentation.

ACKNOWLEDGEMENTS

The authors would like to thank NSF, Rodel, EKC Technology, and the Center for Surface Engineering and Tribology for their support of this work.

NOMENCLATURE

h_D	= copper dishing (nm)
E	= elastic modulus of pad (Pa)
ϕ_x, ϕ_s	= pressure and shear flow factor
H	= pad thickness (mm)
h	= fluid film thickness (μm)
K_{cu}	= Preston wear coefficient for copper
μ	= fluid viscosity (Pa-s)
P_{app}	= total contact pressure (Pa)
p	= slurry film pressure (Pa)
P_{load}	= line load (N/m)
ξ	= pad conformity constant
S	= removal rate selectivity of Cu/Ta
s	= pad roughness (μm)
σ	= applied contact stress (Pa)
t	= overpolishing time (s)
U	= linear pad velocity (m/s)
w	= line width of Cu (μm)
w_o	= minimum effective line width (μm)

REFERENCES

1. Levert, J., S. Danyluk, and J. Tichy, *Mechanism for subambient interfacial Pressures while Polishing with Liquids*. Journal of Tribology, 2000. **Vol.122**: pp. 450.
2. Levert, J., Baker, A., Mess, F., Danyluk, S., Salant, R., Cook, L., *Slurry Film Measurements for Chemical Mechanical Polishing*. Proc. of the Am. Soc. of Precision Engineering, 1996. **Vol.14**: pp. 80.
3. Shan, L., Levert, J., Meade, L., Tichy, J., Danyluk, S., *Interfacial Fluid Mechanics and Pressure Prediction in Chemical Mechanical Polishing*. Journal of Tribology, 2000. **Vol.122**: pp. 539-543.
4. Singer, P., *Tantalum, Copper and Damascene: The future of Interconnects*. Semiconductor International, 1998. **Vol. 21**: pp. 91-98.
5. Yang, L., *Modeling CMP for copper dual damascene interconnects*. Solid State Technology, 2000: pp. 111.
6. Patir, N. and H. Cheng, *An Average Flow Model for Determining Effects of Three-Dimensional Roughness on Partial Hydrodynamic Lubrication*. ASME J. Lubr. Technol., 1978. **Vol. 100**(1): pp. 12-17.