Materials Science and Engineering B 110 (2004) 64–67

MATERIALS SCIENCE & ENGINEERING B

www.elsevier.com/locate/mseb

# Structural investigations of gold-to-gold wafer bonding interfaces

Hyoun Woo Kim*, Nam Ho Kim

*School of Materials Science and Engineering, Inha University, 253 Yong-Hyun-Dong, Nam-Ku, Incheon 402-751, South Korea*

Received 14 November 2003; accepted 4 March 2004

**Abstract**

We have reported the wafer bonding of gold (Au)–Au at 400 °C using the simple furnace and have investigated the structural properties of the Au-bonded layer. Scanning electron microscopy indicated that the bonding interface was clear and straight and the average interfacial grain size of Au-bonded layer increased by the wafer bonding. X-ray diffraction revealed that the lattice plane spacings of interfacial grains decreased by the wafer bonding and the bonded Au layer tended to show the (2 2 0) preferred grain orientation.


*Keywords:* Wafer bonding; Au; Bonding interface; Structural characterization

## 1. Introduction

Gold (Au) thin films, due to its inertness, have potential applications in reflective optics from infrared to X-ray region [1], substrates for scanning tunneling microscopy, and in corrosion prevention, wear protection, and biosensing devices [2]. Recently, the Au film has been studied for interconnection in integrated circuit fabrication due to its high conductivity. Since wafer bonding may also have a niche in integrated circuits by making possible the integration of devices fabricated with different technologies, Au wafer bonding is a very attractive candidate in the implementation of future 3-dimensional integrated circuits.

Although there are numerous papers describing wafer bonding of various materials, such as Si–Si [3,4], GaAs–GaAs [5], GaAs–Si [6,7], AlGaInP–GaP [8], GaAs–sapphire [9], SiC–Si [10,11], $Bi_4Ti_3O_{12}$–Si [12], $Gd_3Ga_5O_{12}$–InP [13], there are only few reports on the metal-to-metal wafer bonding [14,15].

In this study, we investigate the wafer bonding of sputter-deposited Au thin films depending on the bonding temperature in the range of 250–600 °C. Since understanding and controlling the interfacial microstructures are important not only for the materials science but also for the future application, we investigate the structural properties of bonded layers by scanning electron microscopy (SEM) and X-ray diffraction (XRD).

## 2. Experimental

About 100–120 nm of Au layers were deposited by the radio frequency magnetron sputtering on p-type (1 0 0) 4 in. Si wafers. Fig. 1 shows the schematic diagram of the vertical furnace with a quartz tube, used for wafer bonding experiments. After the wafers were cut into the pieces with a dimension of 10 mm × 10 mm, the two samples were loaded Au surface-to-Au surface onto the lower sample holder. Subsequently, the lower holder moved upward and contacted with the upper holder, pressing and bonding the samples face-to-face under a pressure of $5 \times 10^4$ mbar (5 MPa) for 5 min. During the bonding processes, the temperature was set at 250–600 °C in an argon ambient with a flow rate of 1 standard liter per minute. Bonding experiments revealed that the efficiency of wafer bonding depended on the wafer bonding temperature at the fixed pressure. The samples were successfully bonded at 400 and 600 °C and the bonded layers could not be delaminated by a manual grinding, while they were easily separated after the wafer bonding at the lower bonding temperature of 250 °C.

The cross-section and surface morphologies of Au layers before and after bonding were examined with scanning electron microscopy (SEM) (Hitachi S-4200) and the crystallography of the Au layers were analyzed by X-ray diffraction

* Corresponding author. Tel.: +82-32-860-7544; fax: +82-32-862-5546.
*E-mail address:* hwkim@inha.ac.kr (H.W. Kim).

0921-5107/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.mseb.2004.03.004

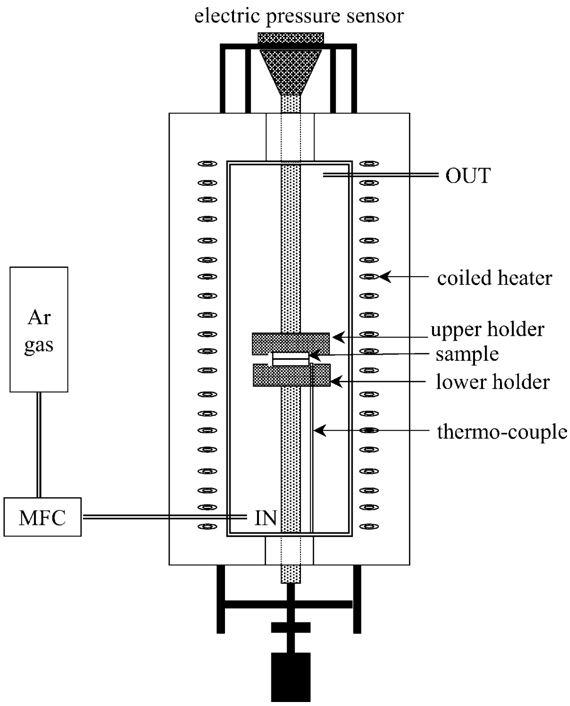


Fig. 1. Schematic diagram of a vertical furnace used for the wafer bonding.

(XRD) using Cu K$\alpha_1$ radiation ($\lambda = 0.154056$ nm). In order to observe the bonding interface using XRD and SEM, we have removed the one-side sample.

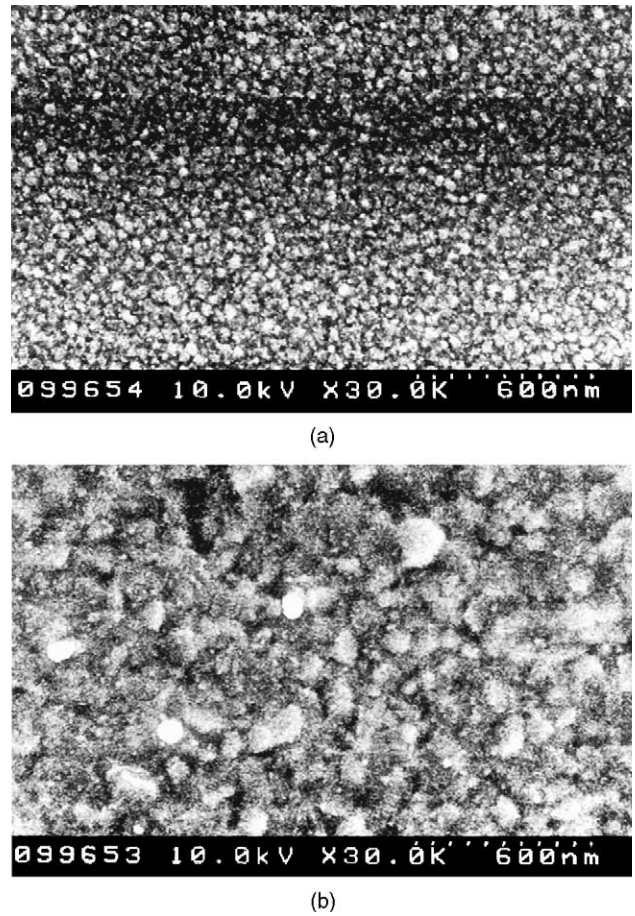


Fig. 3. Plan-view SEM images of (a) as-deposited Au layer and (b) bonded Au layer at 400 °C, revealing the enhanced grain after the wafer bonding.

## 3. Results and discussion

The two Au/Au films, each with film thickness of about 100–120 nm, were found to be bonded to each other over a whole sample area (10 mm × 10 mm). Fig. 2 shows the typical cross-sectional SEM images of Au layers after bonding at 400 °C and the as-deposited Au layer (inset). Cross-sectional SEM images indicate the clear and straight bonding interface.Fig. 3a and b show the plan-view SEM images of as-deposited and bonded Au layer, respectively,

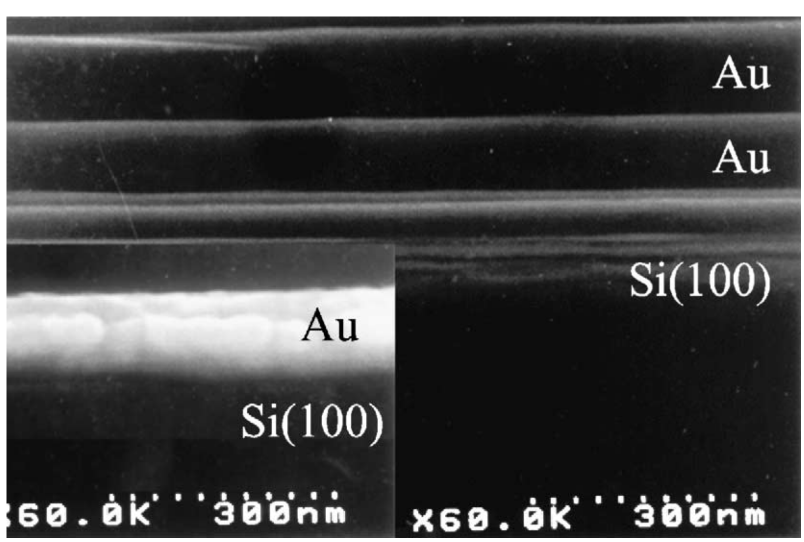


Fig. 2. Cross-sectional SEM images of Au−Au-bonded layer at 400 °C (Inset: cross-sectional SEM images of as-deposited Au layer).

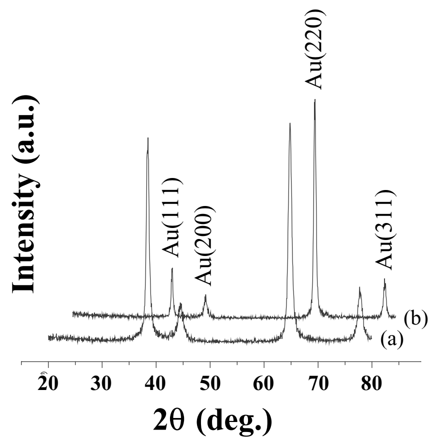


Fig. 4. XRD patterns for (a) as-deposited and (b) bonded Au layer.

indicating that the average grain sizes at the bonding interface become larger by the wafer bonding at 400 °C.

In order to investigate the changes in relative intensities and the 2$\theta$ peak angles of diffraction peaks of Au-bonded layer by the wafer bonding, we have employed the XRD.Fig. 4a and b show the $\theta$–2$\theta$ XRD patterns of the as-deposited and bonded Au layer, respectively, indicating that both layers are polycrystalline in face-centered cubic (fcc) phase with (1 1 1), (2 0 0), (2 2 0), and (3 1 1) diffraction peaks. In the as-deposited Au layer, the relative intensities of (1 1 1) and (2 2 0) peaks are distinguishably strong compared to other peaks. It is noteworthy that the relative intensities of (1 1 1) and (2 2 0) diffraction peaks, compared to other peaks, become weaker and stronger, respectively, after the wafer bonding at 400 °C and accordingly the bonded Au layer tend to show the (2 2 0) preferred grain orientation with the ⟨2 2 0⟩ direction perpendicular to the film plane. We surmise that the grains with (2 2 0) orientation is expected to have lower yield stresses than (1 1 1) grains and thus (2 2 0) grains will tend to grow before (1 1 1) grains and may therefore have an energetic advantage for further growth, by minimizing the strain energy of the Au films [17] (We define ($h\,k\,l$) grains as grains with a ($h\,k\,l$) plane parallel to the film surface.). Although previous researchers have reported the similar observation on the grain orientation in other metal systems such as the copper (Cu)-to-Cu [14] and platinum (Pt)-to-Pt [15] wafer bonding, further systematic study is necessary to reveal the detailed mechanism of grain orientation during the Au wafer bonding process.

Fig. 5a–d, respectively, represent the (1 1 1), (2 0 0), (2 2 0), and (3 1 1) diffraction peaks of as-deposited and 400 °C-bonded Au layers, indicating that the peak angle (2$\theta$) of the (1 1 1), (2 0 0), (2 2 0), and (3 1 1) diffraction peaks, respectively, changes from 38.42 to 38.48°, from 44.48 to 44.68°, from 64.80 to 64.94°, and from 77.80 to 77.91°, by wafer bonding at 400 °C. Since the peak angles of observed diffraction peaks increase by the wafer bonding and larger

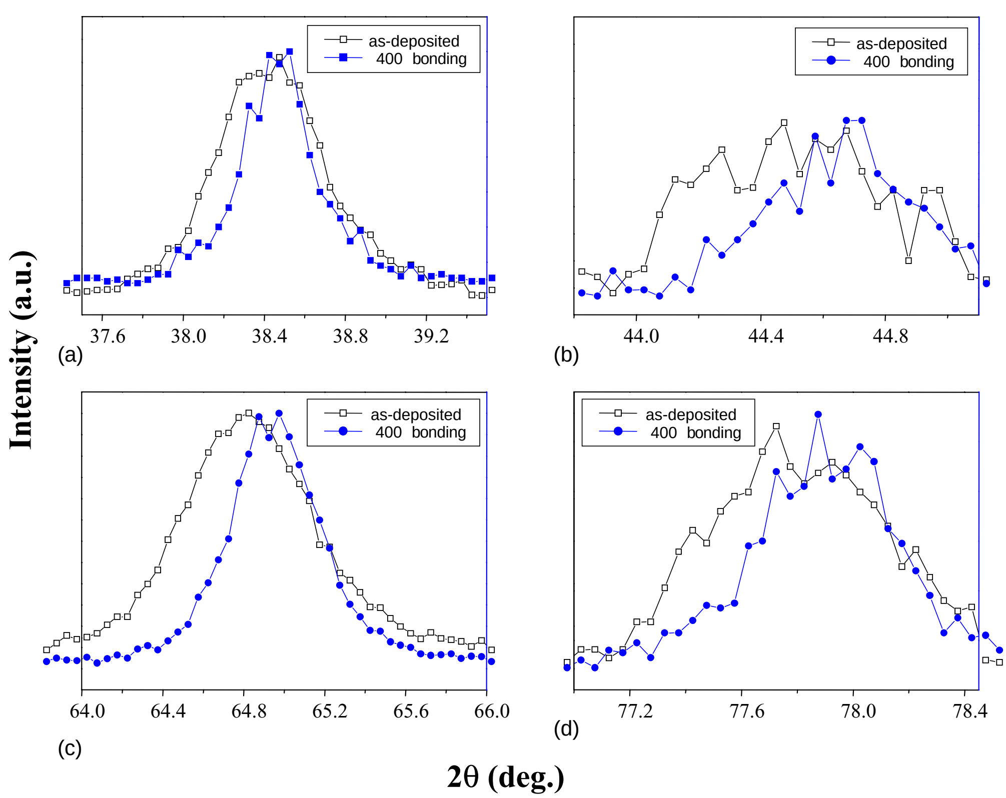


Fig. 5. Portions of X-ray diffraction spectra, revealing the (a) (1 1 1), (b) (2 0 0), (c) (2 2 0), and (d) (3 1 1) diffraction peaks of as-deposited and 400 °C-bonded layers.

peak angle corresponds to the smaller lattice plane spacing by the Bragg's law [16], we reveal that the lattice plane spacing is reduced by the wafer bonding at 400 °C. As our previous experiments indicated that the 400 °C-annealed Au layer without bonding showed the similar increases of the peak angles to the 400 °C-bonded layer within experimental error (not shown here), we surmise that the crystal mismatch and difference of thermal expansion between Si and Au might have caused the changes of the lattice plane spacing in the Au films.

## 4. Conclusions

In summary, we have demonstrated the bonding of the Au thin film onto the Au layer on the Si(1 0 0) substrate. Investigation of the bonding interface with the bonding temperature of 400 °C indicates that the relative intensities of (1 1 1) and (2 2 0) peaks, compared to other peaks, decreases and increases, respectively, with the wafer bonding. The average grain size and the lattice plane spacings increase and decrease, respectively, with the wafer bonding. The feasibility of Au-to-Au wafer bonding and its structural characterization will contribute to the development of interconnection technology for future integrated circuits.

## Acknowledgements

This work was supported by INHA UNIVERITY Research Grant (INHA-30188).

## References

[1] J. Garnaes, F.E. Christensen, F. Besenbacher, E. Laegaggaard, I. Stensgard, Opt. Eng. 29 (1990) 666.
[2] D.J. Campbell, B.R. Herr, J.C. Hulteen, R.P. Van Duyne, C.A. Mirkin, J. Am. Chem. Soc. 118 (1996) 10211.
[3] J.B. Lasky, Appl. Phys. Lett. 48 (1986) 78.
[4] P.W. Barth, Sens. Actuators A 21–23 (1990) 919.
[5] A. Yamada, M. Oasa, H. Nagabuchi, M. Kawashima, Mater. Lett. 6 (1988) 167.
[6] J. Haisma, B.A.C.M. Spierings, U.K.P. Biermann, A.A. van Gorkum, Appl. Opt. 33 (1994) 1154.
[7] J.F. Klem, E.D. Jones, D.R. Myers, J.A. Lott, J. Appl. Phys. 66 (1989) 459.
[8] F.A. Kish, F.M. Steranka, D.C. DeFevere, D.A. Vanderwater, K.G. Park, C.P. Kuo, T.D. Osentowski, M.J. Peanasky, J.G. Yu, R.M. Fletcher, D.A. Steigerwald, M.G. Craford, V.M. Robbins, Appl. Phys. Lett. 64 (1994) 2839.
[9] P. Kopperschmidt, G. Kästner, S. Senz, D. Hesse, U. Gösele, Appl. Phys. A 64 (1997) 533.
[10] K.N. Vinod, C.A. Zorman, A.A. Yasseen, M. Mehregany, J. Electron. Mater. 27 (1998) L17.
[11] Q.-Y. Tong, U. Gösele, C. Yuan, A.J. Steckl, M. Reiche, J. Electrochem. Soc. 142 (1995) 232.
[12] M. Alexe, G. Kästner, D. Hesse, U. Gosele, Appl. Phys. Lett. 70 (1997) 3416.
[13] M. Totoki, T. Mizumoto, K. Maru, Y. Naito, Electron. Lett. 30 (1994) 1534.
[14] K.N. Chen, A. Fan, C.S. Tan, R. Reif, C.Y. Wen, Appl. Phys. Lett. 81 (2002) 3774.
[15] T. Shimatsu, R.H. Mollema, D. Monsma, E.G. Keim, J.C. Lodder, J. Vac. Sci. Technol. A 16 (1998) 2125.
[16] B.D. Cullity, Elements of X-ray Diffraction, Addison-Wesley, Reading, MA, 1978, p.100.
[17] C.V. Thompson, R. Carel, J. Mech. Phys. Solids 44 (1996) 657.