Silicon Micro-probe Card Using Porous Silicon Micromachining Technology

Young-Min Kim, Ho-Cheol Yoon, and Jong-Hyun Lee

We present a new type of silicon micro-probe card using a three-dimensional probe beam of the cantilever type. It was fabricated using KOH and dry etching, a porous silicon micromachining technique, and an Au electroplating process. The cantilever-type probe beam had a thickness of 5 μm, a width of 50 μm, and a length of 800 μm. The probe beam for pad contact was formed by the thermal expansion coefficient difference between the films. The maximum height of the curled probe beam was 170 μm, and an annealing process was performed for 20 min at 500°C. The contact resistance of the newly fabricated probe card was less than 2 Ω, and its lifetime was more than 20,000 turns.

Keywords: Silicon probe card, probe beam, porous silicon micromachining, contact resistance.

I. Introduction

Recently, as high performance integrated circuits (ICs) are requiring a larger number of input and output pads, as well as higher operating speeds, semiconductor device dimensions are shrinking and complexity increasing. As a result, the number of probes has trended to increase, due to the decreasing size and spacing of the pads [1], [2]. The traditional probe card is difficult to adapt for the higher pad-density IC test. In order to solve these problems, several attempts to fabricate a probe card using semiconductor fabrication techniques [3], [4] have been conducted.

A membrane probe card has been developed as a substitute for probing high-density IC chips [5], [6]. Although the membrane probe card has some advantages compared to the traditional probe card with needles, it also has limitations. The first disadvantage is that the flexibility and elongated characteristics of the membrane are not fully suitable. Secondly, as a result of the first disadvantage, all the probe points on the membrane probe card cannot contact the chip simultaneously with a single applied force. Finally, because the membrane probe card cannot scrub the metal of IC chips, the contact resistance is higher than that of the traditional probe card [7]-[9]. Also, a cantilever-type MEMS (micro-electromechanical systems) probe card was first developed by Zhang and others, but the problem of the probe card can not endure or produce the force required to break the oxide on a metal pad surface [8].

In this paper, we propose a new fabrication process for a silicon micro-probe card that consists of an array of probe beams. The metal pads of the probe card are located on the KOH etched surface in order to extract the lead wire from the backside of the probe card. To form a probe beam, we used a porous silicon micromachining process using the property of a

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Young-Min Kim (phone: +82 53 940 8619, email: rockeyk@lycos.co.kr) was with Department of Electronics, Kyungpook National University, Daegu, Korea. He is now with Korea Abrasive Ind. Co. Ltd., Incheon, Korea.

Ho-Cheol Yoon (email: hcyoon@koreaabrasive.com) is with Korea Abrasive Ind. Co. Ltd., Incheon, Korea.

Jong-Hyun Lee (email: jhlee@ee.knu.ac.kr) is with School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu, Korea.

silicon wafer [10]-[13]. Probe beams were curled up as a result of surface tension and the difference in the thermal expansion coefficients between the thin films on the probe beams. To measure the electrical and mechanical characteristics of the probe card, we tried to contact it on the Al pad and Au pad.

II. Design and Fabrication

Figure 1 illustrates a schematic of the proposed silicon micro-probe card, consisting of a silicon-type probe beam, ceramic plate, and printed circuit board (PCB) for the electrical connection. The electrical and mechanical characteristics of the probe card were measured using a scrubbing motion in a horizontal direction.

The width of the probe beam was 40 to 60 μm. The thickness and length of the probe beam were 5 and 800 μm, respectively. The open area of a via hole was 900 × 900 μm^2. A via hole was used for electrical connection with the PCB. We fabricated a probe card using KOH wet etching, deep reactive ion etching (DRIE), porous silicon micromachining, and an electroplating process. The deflection height of the probe beam was measured as a function of the annealing temperature and time.

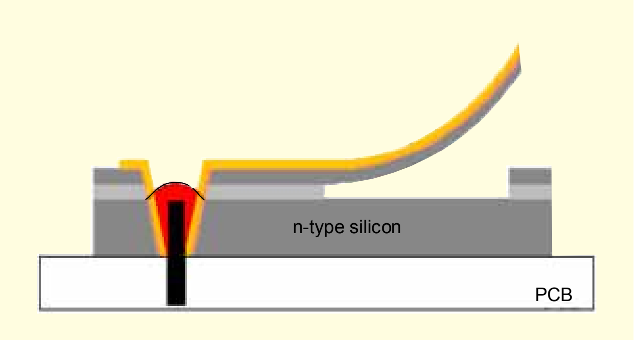
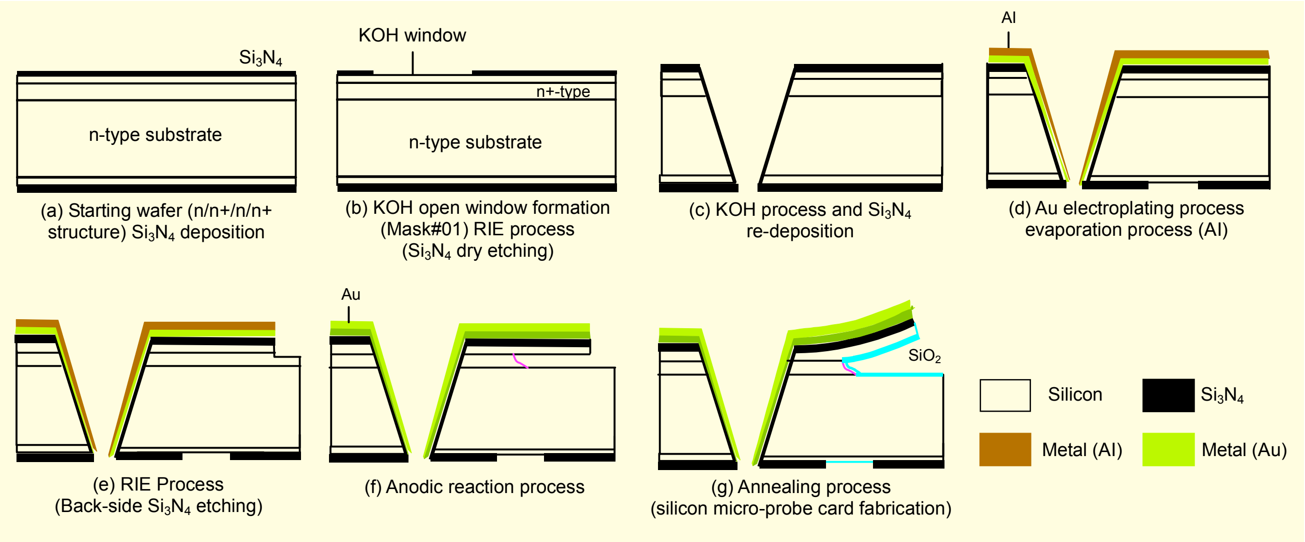


Fig. 1. A schematic of the proposed silicon probe card.

A detailed sequence for the fabrication of the probe card is shown in Fig. 2. The initial material was a 5-inch (100) silicon wafer with a thickness of 450 μm. We began with a diffusion to make a highly doped n$^+$ layer over an n-type substrate and the subsequent growth of a lightly doped n-epitaxial layer. The thickness of the n$^+$ diffusion layer and n-epitaxial layer were 20 and 5 μm, respectively. The substrate for fabricating the micro-probe card was a n/n$^+$/n-sub/n$^+$ structure. Then, silicon nitride (Si_3N_4) 1,500 Å thick, was deposited by low-pressure chemical vapor deposition as shown in Fig. 2(a). First, in order to connect the lead wire from the backside of the wafer, the patterned via hole on the wafer was etched through from the front-side using a KOH solution, as shown in Figs. 2(b) and 2(c). Au (500 Å) and Ni-Cr (2,000 Å) were deposited on Si_3N_4 as seed and adhesion layers, respectively. A further Ni-Cr thin film was used for thermal stress to deflect the probe beam. After forming the electroplating mold using a thick photoresist (SU-8), the metal lines were fabricated by the Au electroplating process. Then, 0.2 μm thick aluminum was deposited using a thermal evaporator to protect the probe beam during DRIE, as shown in Fig. 2(d). Next, the probe beams and anodic reaction window were patterned; a dry etching was performed immediately after, as can be seen in Fig. 2(e). A porous silicon layer (PSL) was then formed on a 20 μm thick n$^+$ diffused layer by anodization, where the anodic reaction was performed in 43 wt.% aqueous HF solution for 25 min at room temperature by applying a constant current density of 10 mA/cm^2. The PSL was subsequently removed into a 5 wt.% NaOH solution, as shown in Fig. 2(f). Since the doping concentration in the n$^+$



(a) Starting wafer (n/n+/n/n+ structure) Si_3N_4 deposition

(b) KOH open window formation (Mask#01) RIE process (Si_3N_4 dry etching)

(c) KOH process and Si_3N_4 re-deposition

(d) Au electroplating process evaporation process (Al)

(e) RIE Process (Back-side Si_3N_4 etching)

(f) Anodic reaction process

(g) Annealing process (silicon micro-probe card fabrication)

Fig. 2. Fabrication process of a micro-probe card.

diffused layer was much higher than that in the n-epitaxial layer and substrate, the anodic reaction only occurred in the n^+ diffused layer. Finally, to obtain even more curled probe beams, we performed an annealing process, illustrated in Fig. 2(g).

The probe beams were curled up as a result of surface tension and the difference in the thermal expansion coefficients between the thin films. The micro-probe card was fabricated using the proposed process [10].

III. Results and Discussion

Figure 3 shows a surface scanning electron microscopy (SEM) image of the probe beam before the annealing process. The thickness of the silicon epitaxial layer was 5 μm and the probe beam was a Au/Ni-Cr/Si_3N_4/n-epi structure.

The probe beams were fabricated using a porous silicon micromachining technique. Since the anodic reaction does not proceed to the lightly doped n-type substrate, the reaction stops automatically after the complete conversion of the n^+ region to porous silicon.

Figure 4 shows an SEM image of the probe beam after the annealing process. To obtain an even more curled probe beam, the probe card was annealed in nitrogen ambient for 20 min at 500 °C.

The results showed that a deflection of 170 μm could be achieved with a silicon epitaxial thickness of 5 μm. The width and length of the probe beam were 50 and 800 μm, respectively. Furthermore, the probe beams achieved a uniform radius curvature. The probe beam was more curled due to the difference in the thermal expansion coefficient between the films.

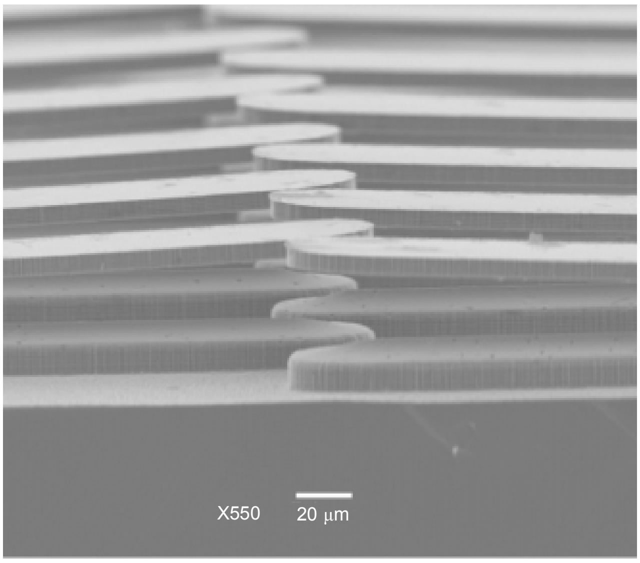


Fig. 3. Cross-sectional SEM image of micro-probe beam before the annealing process.

Fig. 4. Cross-sectional SEM image of micro-probe beam after the annealing process.

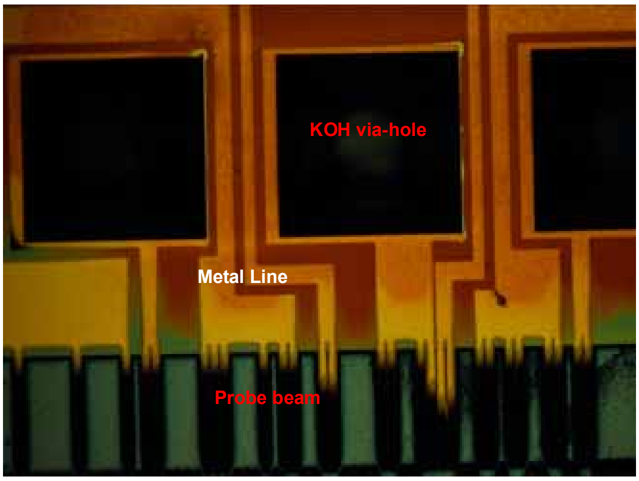


Fig. 5. Photograph of the array probe card with a KOH via hole.

A photograph of the silicon micro-probe card is shown in Fig. 5. It consists of both probe beam and via hole. The open area of the via-hole fabricated by KOH process was 900 × 900 μm^2. The via-hole was used to connect with the PCB. The metal pads of the probe card were located on the KOH etched surface in order to extract the lead wire from the backside of the probe card. The air gap between probe beams and the substrate was 20 μm, which enabled the probe beam to bend for the touchdown test.

The efficacy of a probe card can be divided into its mechanical and electrical performance, including its contact resistance, signal speed, overdrive, and so on. In addition, the probing environment, probe card lifetime, and maintenance process are also very important factors. As such, this paper focuses on the fabrication process of a micro-probe card using a silicon wafer, then measures the electrical and mechanical characteristics, such as the contact resistance, overdrive, and force.

The force required for an ohmic contact is difficult to model because of two factors: the uncertainty of the contact area and the effect of interfacial insulating layers, such as oxide or hydrocarbon contamination. As such, a range of applied forces has been reported, depending on the circumstances. For example, a force of over 100 mN has been reported for conventional spreading-resistance probe contacts in order to make a contact with Al electrodes [9].

The overdrive is the moved distance from the point of initial contact with an IC pad. The force of the probe beams was measured as a function of the overdrive. As such, the probe beams were designed to produce sufficient overdrive, as experimentation confirmed that the force was sufficient to break through the native oxide layer and maintain a low contact resistance.

Figure 6 is a schematic diagram of the contact resistance testing. To make contact with the pads on IC chips during the wafer-stage testing, the probe beams scratch the surface of the metal contact pads.

We studied the total circuit resistance to gold and aluminum pads, with the results shown in Figs. 7 and 8. The resistance of each probe was measured by overdriving the contact set assembly in increments of 10 μm all the way up to 110 μm of overdrive. The mechanical characteristics of the probe beam were studied as a function of the overdrive.

Figure 7 shows the resistance between the Au pad and probe card versus overdrive. Gold is known to not grow a native oxide and does not require any electrical breakdown to achieve a low value of contact resistance. Figure 8 shows the resistance between the Al pad and probe card versus overdrive.

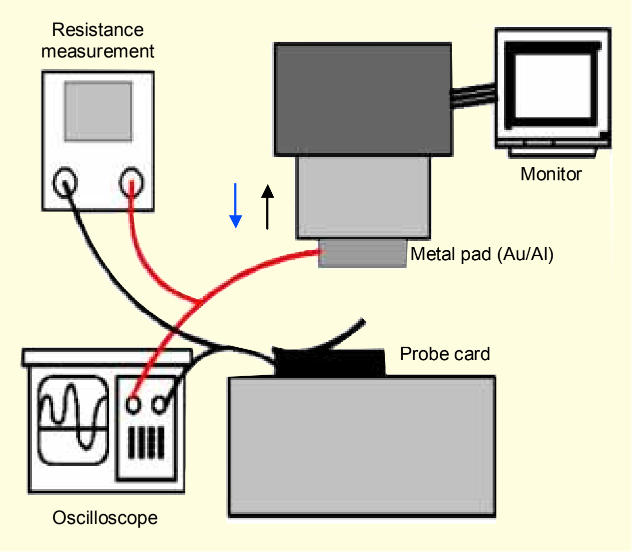


Fig. 6. Measurement system of contact resistance.

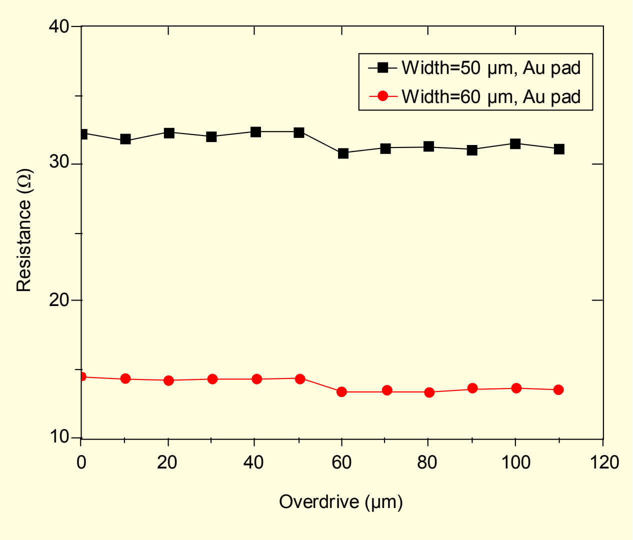


Fig. 7. Resistance on gold wafer versus overdrive.

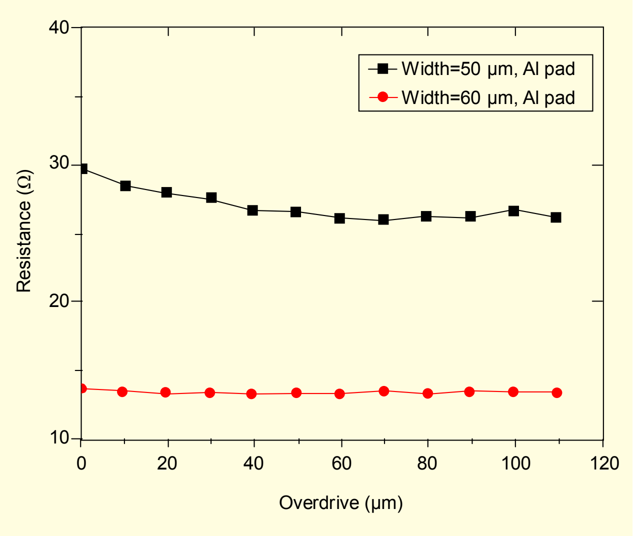


Fig. 8. Resistance on aluminum wafer versus overdrive.

Contact force can be calculated from the probe beam deflection. The probe force can be increased by increasing the beam width without decreasing probe beam deflection. The overdrive was achieved by a bending of the probe beam and was limited by its height after being curled. As a result, we obtained stable resistance values while probing. The mechanical stability of the probe beams was maintained up to 110 μm of overdrive.

A thin aluminum oxide film is grown quickly when exposed to air. In order to contact the pad, a probe beam must receive sufficient force. Figure 9 shows the resistance variety that was measured as a function of overdrive force. The width of the probe beam was 50 μm.

Figure 9 shows the measured resistance variety after removal and formation of a thin aluminum oxide film on the pad surface. We observed that the resistance falls to below 30 ohm after about 40 μm of overdrive, and remains constant with further overdrive. Aluminum pads were also found to require sufficient force to break down the native oxide. Aluminum is known to form a very hardy oxide on a surface. However, on making contact between the probe and the metal pad, as the probe card moves down, the probe beams shift in the X-direction to mechanically scratch the native oxide. In this paper, these results, shown in Figs. 8 and 9, show that a contact force of over 40 μm overdrive can break an aluminum oxide film on the pad.

Figure 10 shows the contact resistance between the Au pad and probe beam versus the number of touchdowns. The widths of the probe beam were 40, 50, and 60 μm, respectively. The length of the probe beam was 800 μm.

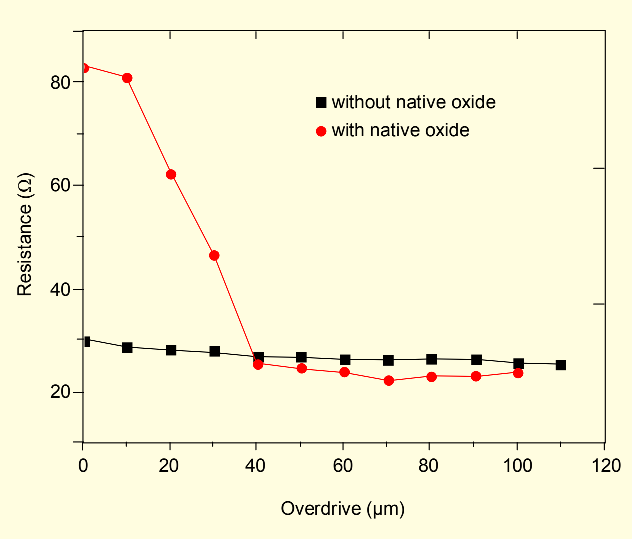


Fig. 9. Resistance characteristics versus overdrive.

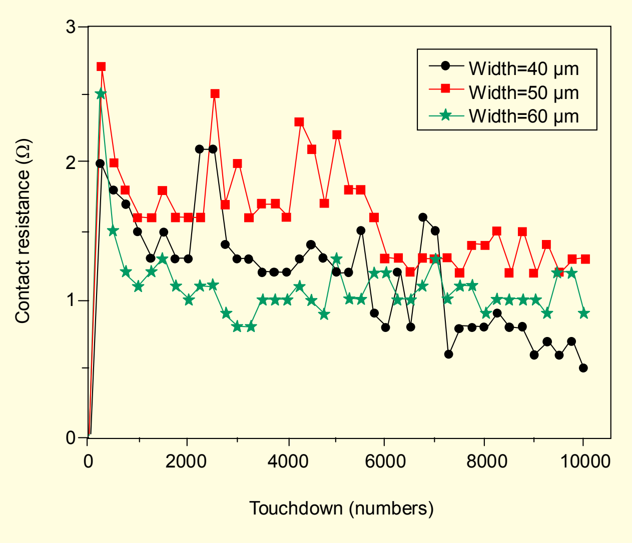


Fig. 10. Contact resistance versus touchdown number.

The contact resistance between a probe beam and a test pad was measured by their direct contact. The probe beams were tested with 40 μm of overdrive. As a result, the contact resistance of the probe beam was measured to be below 2 Ω and there was no change of contact resistance after 20,000 contacts. Also, there was no peel-off of the metal on the top of probe beam.

IV. Conclusions

We have presented a silicon micro-probe card using a three-dimensional probe beam of the cantilever type. It was fabricated using KOH, DRIE, anodic reaction, and an electroplating process. To form a probe beam, we used porous silicon micromachining techniques. In addition, to make low contact resistance, we used an Au electroplating process. The contact resistance of the probe beam was below 2 Ω and there was no change in resistance during 20,000 contacts. The touchdown test was performed more than 20,000 times. The probe beam was not broken up at 100 μm of overdrive, it kept up a constant resistance. The metal pads were defined on the surface etched by KOH, which facilitates the extraction of lead wires from the backside of the wafer. The fabrication process used in this paper was very simple and reproducible. We expect that this fabrication process may also be applied to a fine pitch, multi-array probe card.

References

[1] Shin'ichiro Asai, Kazuo Kato, Noriaki Nakazaki, and Yukihiko Nakajima, "Probe Card with Probe Pins Grown by the Vapor-Liquid-Solid (VLS) Method," *IEEE Trans. Comp., Package. Manufat. Technol.*, part A. vol. 19, 1996, pp. 258-267.

[2] C. Barsotti, S.Tremaine, and M. Bonham, "Very High Density Probing," *Proc. ITC* '88, 1988, pp. 608-614.

[3] Rajiv Pandey and Dan Higgins, "P4 Probe Card-A Solution for at-Speed, High Density, Wafer Probing," *IEEE ITC'* 98, 1998, pp. 836-842.

[4] T. Tada, R. Takagi, S. Nakao, M. Hyozo, T. Arakawa, K. Sawada, and M. Ueda, "A Fine Pitch Probe Technology for VLSI Wafer Testing," *IEEE ITC'90*, 1990, pp. 900-906.

[5] J. Leung, M. Zargari, B.A. Wooley, and S.S. Wong, "Active Substrate Membrane Probe Card," *IEDM'95,* 1995, pp. 424-429.

[6] Mark Beiley, Justin. Leung, and S. Simon Wong, "A Micromachined Array Probe Card-Fabrication Process," *IEEE Trans. Comp., Package. Manufat. Technol.*, part B. vol. 18, no. 1, 1995, pp. 179-183.

[7] Y. Zhang, Y. Whzng, and R.B. Marcus, "Thermally Actuated

Microprobes for a New Wafer Probe Card," *IEEE J. Microelectromechanical Systems*, vol. 8, 1999, pp. 43-49.

[8] B.H. Kim, S.J. Park, B.L. Lee, J.H. Lee, B.G. Min, S.D. Choi, D.I. Cho, and K.J. Chun, "A Novel MEMS Silicon Probe Card," *The 14th IEEE Int'l Conf. on MEMS*, 2002, pp. 368-371.

[9] K. Kataoka, S. Kawamura, T. Itoh, and T. Suga, "Low Contact-Force and Compliant MEMS Probe Card Utilizing Fritting Contact," *The Fifteenth IEEE Int'l Conf. on MEMS*, 2002, pp. 364-367.

[10] Y.M. Kim, C.T. Seo, D.S. Eun, S.G. Park, C.S. Jo, and J.H. Lee, "Characteristics of Cantilever Beam Fabricated by Porous Silicon Micromachining for Flow Sensor Application," *Proc. IEEE Int'l Conf. SENSORS 2003*, 2003, pp. 642-646.

[11] Y.D. Kim, J.H. Sim, J.W. Nam, and J.H. Lee, "Fabrication of a Silicon Micro-Probe for Vertical Probe Card Application," *Jpn. J. Appl. Phys.*, vol. 37, 1998, pp. 7070-7073.

[12] Y.M. Kim, K.Y. Noh, J.Y. Park, Y.D. Kim, I.S. Yu, C.S. Cho, and J.H. Lee, "Fabrication of Oxidized Porous Silicon(OPS) Air-Brdige for RF Application Using Micromachining Technology," *J. the Korean Physical Socity*, 2001, pp. S268-S270.

[13] J.Y. Park and J.H. Lee, "Characterization of Oxidized Porous Silicon Layer by Complex Process Using RTO and the Fabrication of CPW-Type Stubs on an OPSL for RF Application," *ETRI J.*, vol. 26, no. 4, Aug. 2004, pp. 315-320.

Young-Min Kim received the BS and MS degrees in electronic engineering from Cheju National University, Cheju, Korea, in 1990 and 1998, and his PhD degree in electronic engineering from Kyoungpook National University, Daegu , Korea, in 2003. He worked for the Lumsonic Co. and Korea Abrasive Co., Korea, from October 2000 to December 2002 and from March 2003 to December 2004, respectively. He has been engaged in research on silicon micro-probe card for IC chip tests. Since 2005, he has been with SYHITECH Co., Korea, as a Senior Manager of R&D Center, where he has been engaged in research on semiconductor sensors. His research interests are in microelectromechanical system (MEMS)-based RF passive devices, silicon probe cards, microsensors, and MEMS fabrication processes.

Ho-Cheol Yoon received the BS and MS degrees in chemical engineering from KyungHee University, Seoul, Korea, in 1981 and 1983, and the MBA degree in business management from Ashland University, Ohio, USA in 1985. He has worked for the Korea Abrasive Co., Korea, and he is now a CEO. His research interests are in MEMS-based silicon probe cards, and MEMS fabrication processes.

Jong-Hyun Lee was born in Korea in 1949. He attended Kyungpook National University (KNU) where he received the BS and the MS degrees in electronics engineering in 1972 and 1976. He was awarded his Docteur d'Ingenieur in electronics from ENSERG-INP, Grenoble, France, in 1981. He joined the School of Electronic & Electrical Engineering at KNU, in 1982, where he taught courses in semiconductor physics, electronic devices, integrated circuits fabrication process, and electronic materials. Between 1994 and 1997, he served as Director of the school, and he is now a Professor. From 1985 to 1986, he was employed at ENSERG-INP, in France, as a professeur associe, where he participated in research on silicon-on-insulator. He is now actively engaged in research on semiconductor sensors, micro-machined devices, nano-structures, and their applications.