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Research paper

Probe Array from BeCu Metal Sheet Using Heat and Fusing Currents

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Abstract

A probe array fabricated from a beryllium-copper metal sheet was developed in order to produce cost-effective microelectromechanical system (MEMS) probe cards. The probe array is fabricated via a simple, inexpensive process in which a heat current is used for annealing and a fusing current from a DC power supply is used for cutting the metal sheet. The stress relaxation time was 7 min during the application of a 4 A heat current, and the fusing current was 20 A. The contact force was approximately 1 gram force at a deflection of 100 µm, and the contact resistance from the tip of the probe to the end of the probe beam was 1.9 Ω. The probe array is suitable for use in probe cards, test sockets, and various types of manufacturing equipment.

Keywords: *BeCu; probe array; heat current; fusing current*

1. Introduction

Probe cards are used during single-touchdown or multi-touchdown tests of semiconductor wafers up to 300 mm in diameter in order to reduce testing costs. The integrated circuits (ICs) fabricated on semiconductor wafers are becoming faster and more complex, and the number of input/output pads is increasing dramatically; consequently, ICs are becoming larger. The resulting increase in wafer size means that probe cards must also become larger and thus more expensive. Various types of probe cards are manufactured, including epoxy, blade, vertical, array, and microspring types [1-8]. The emerging microspring microelectromechanical system (MEMS) probe card is beginning to dominate wafer testing [9-12]. These cards can achieve fine-pitch, multi-device-under-test (multi-DUT) performance and one- or minimum-touchdown wafer testing. Tray et al. [9] demonstrated a microspring fabricated via a customized wire bonding technique. Hantschel et al. [10] reported on connectors using stress mismatch caused by two metal beam layers. Jing et al. [11] and Tsou et al. [12] reported on probe tips that incorporated electroplated Ni. However, most of them are difficult to make connectors uniformly because of different stress of beam layers. MEMS probe cards are more expensive to produce than conventional probe cards. However, this paper presents an inexpensive fabrication process that uses BeCu metal sheets and solder-ball filling of via holes. A probe card typically consists of a probe contact element, a multilayer ceramic substrate, an interposer, and a printed circuit board. The probe contact element, also called the probe tip or probe, is very important for fine-pitch and multi-DUT testing.

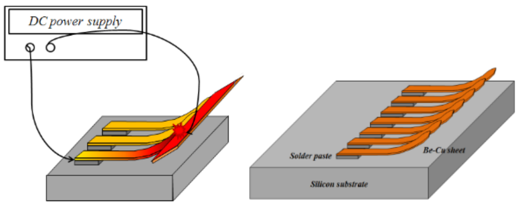

Figure 1: Formation of the proposed BeCu probe array using heat and fusing currents.

In this study, a heat current and a fusing current are used to fabricate low-cost probe cards. As current flows through a conductor, some electrical energy is converted to heat, supplying thermal energy to the conductor. This process is called Joule heating. Joule heating is caused by interactions between the moving particles that form the current and the atomic ions that make up the body of the conductor. When the temperature of the heated conductor reaches equilibrium with the external temperature, the heated conductor exhibits stress relaxation as a result of the applied current. The heat current is expressed as the rate of heat exchange between molecules. The fusing current of a wire is the current that will cause it to overheat, melt, and thus create an open circuit; in this case the wire is acting like a fuse [13, 14]. The fusing current affects the circuit as follows. First, as the current increases, the fuse element heats up; eventually it melts and falls away. An arc forms between the ends of the element. As the ends melt away, the arc becomes longer. Eventually, the gap is too long for the arc, and current stops flowing.

The probe beam is formed by raising up a BeCu metal sheet and annealing it using the heat current; this deforms the probe array into a stress-free beam. Table 1 lists the properties of BeCu, which is widely used as a material for electrical connectors and probes because it has a high elastic modulus and high hardness and can be shaped into sheets having various sizes, with thicknesses from 10 µm to 100 µm [15-17]. The probe array is then cut from the BeCu

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metal sheet by applying the fusing current. Figure 1 shows the proposed BeCu probe array.

2. Design

The probe array had dimensions of 2 cm × 2 cm and was positioned on a silicon substrate; the pitch of the tip was 1.2 mm. The probe beam was designed by applying simple calculation and simulation results [15-17] to obtain the optimal deflection and contact force. Figure 2 shows the deflection of the beam as a function of the applied force and beam length. When the applied force increases from 1 gram force (gf) to 2 gf, the deflection of the beam increases. However, the stress, which is proportional to the deflection, also increases. The increase in stress is disadvantageous because the probe beam undergoes plastic deformation when it is overstressed. Thus, the probe beam was designed to deflect by 100–300 µm at 1 gf; its calculated deflection was 272 µm under application of 1 gf. On the basis of calculations and ANSYS simulation results, a probe length and width of 1.7–2.1 mm and 500 µm, respectively, were chosen. The designed width and length of the end point of the probe tip were 50–90 µm and 10–20 µm, respectively. The via holes were 400 µm in diameter, and the metal shadow mask had dimensions of 450 µm × 450 µm.

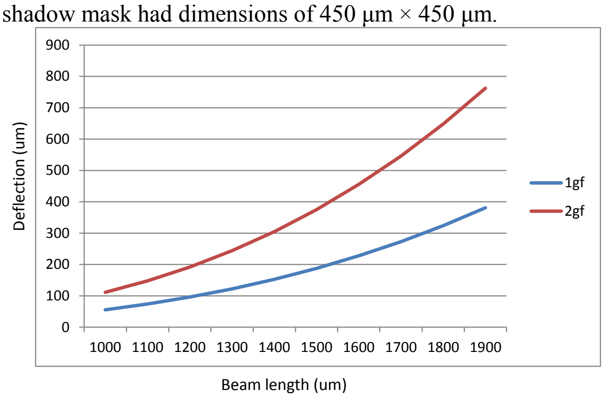


Figure 2: Deflection of the probe beam as a function of its length.

3. Fabrication

Figure 3 shows the fabrication process for the BeCu probe card. The starting material was a 6-inch-diameter, 400-µm-thick, double side polished p-type silicon wafer. A 1.6-µm-thick SiO_2 layer was thermally grown on the wafer after organics and fine dust on the silicon surface were removed. The SiO_2 layer was etched using a buffered oxide etch solution after photolithography with AZ 9260 photoresist.

The silicon wafer was thoroughly etched using deep reactive ion etching. It was then insulated with a 1 µm SiO_2 layer deposited via plasma-enhanced chemical vapor deposition. To facilitate the soldering process, 100 nm nickel and 150 nm gold seed layers were deposited by an e-beam evaporator. Next, the via holes were filled with $Ag_3Sn_{96.5}Cu_{0.5}$ solder paste. After the solder paste was subjected to reflowing at 380°C for 5 min, the same solder paste was used as a bonding material to fill the tops of the via holes. For forming the probe array, the back of the BeCu metal sheet was coated with dry film resist to protect it from back-side attack when the probe array was wet-etched. The BeCu metal sheet was etched with $FeCl_3$ solution after photolithography with AZ 1512 photoresist to form the probe array. In regard to bonding the two substrates, Figure 4 shows the process of bonding, annealing, and cutting the probe array [13, 18]. The BeCu metal sheet and silicon substrate were bonded with solder paste under the reflow conditions described above (see Figure 4(a)). Next, the BeCu metal sheet was raised to 500 µm using ruler and then annealed by applying a 4 A heat current for 7 min. There is no initial deflection before annealing via heat current. Finally, the probe array was fused by applying a 20 A current for less than 10 s. The conditions for annealing and fusing were chosen based on the results described in the following section.

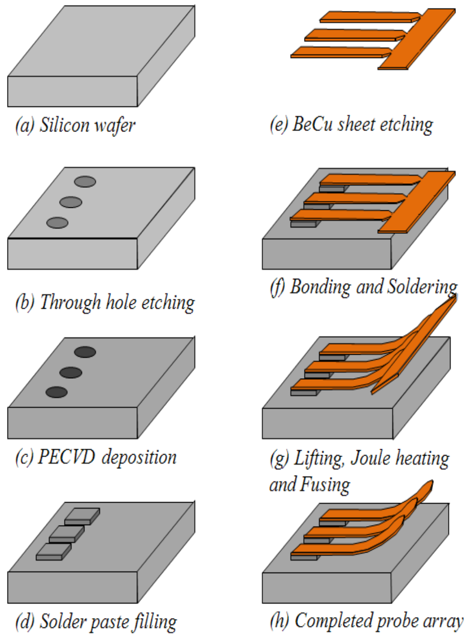


Figure 3: BeCu probe array fabrication.

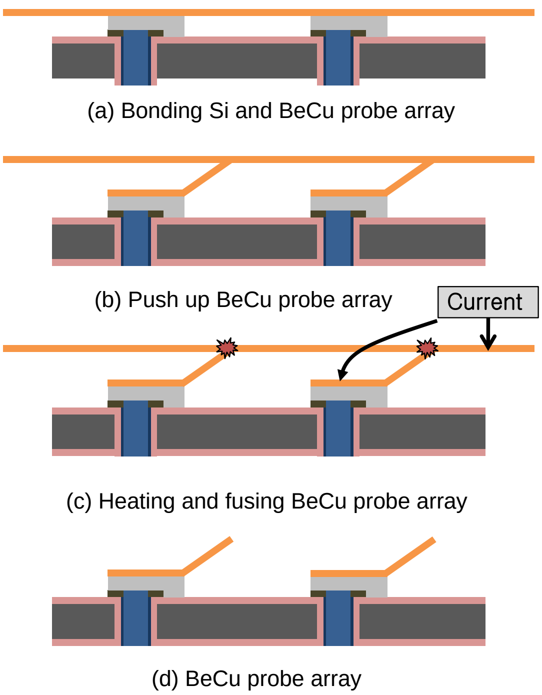
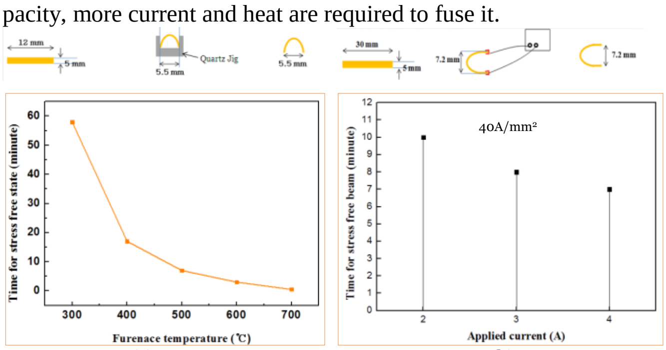


Figure 4: Bonding between BeCu and silicon substrate and formation of BeCu probe array using heat and fusing currents.

4. Results and Discussion

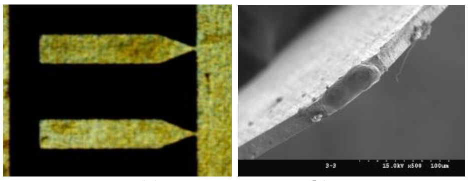
4.1 Stress Relaxation Test Using Heat Current

Stress relaxation can be achieved through annealing or current application. Annealing can be achieved by using a furnace. As shown in Figure 5(a), a BeCu beam was bent and placed in a quartz jig. Then, the BeCu beam was annealed for 1 h. The graph shows the time required to obtain a stress-free beam. The time indicated on the graph corresponds to when the distance between the ends of the beam was the same as the initial distance, i.e., 5.5 mm. The relaxation characteristics as a function of time were also investigated using an applied DC current. In order to verify the method of annealing via heat current, an experiment was performed using BeCu beams. The dimensions of the BeCu beam were 30 mm × 5 mm. The beam was bent, and the ends of the bent beam were 7.2 mm apart [13, 18]. Current was applied to both ends of the beam to perform the annealing. After a 24 h period, the distance between the ends was measured and compared to that before annealing. The annealing time required to obtain a stress-free beam in relation to applied current profile is shown in Figure 5(b). When the applied current density was 40 A/m^2, the current and duration that produced a stress-free beam were approximately 4 A/mm^2 and 7 min, respectively. In accordance with these results, a heat current of 4 A was applied for 7 min during fabrication of the BeCu probe array, and then the array was instantaneously fused with a current of 20 A. Figure 6 shows optical and scanning electron microscopy (SEM) images of the fabricated probe array. Images of the cutting planes formed at the BeCu edges under overcurrent conditions are also shown. The larger cutting plane (70 µm × 15 µm) had a more irregular shape, and the BeCu was more scattered than in the smaller cutting plane (50 µm × 15 µm). Because the larger cutting plane has greater current and heat capacity, more current and heat are required to fuse it.

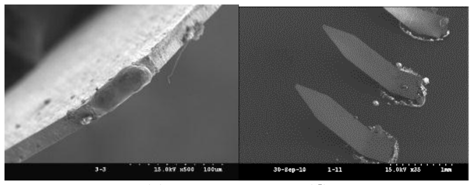


(a) (b)

Figure 5: Comparison of the stress relaxation of a BeCu beam heated by (a) a furnace and (b) an applied current.



(a) (b)



(c) (d)

Figure 6: Fabricated probe array. (a) Optical image. (b) and (c) SEM images of cutting planes with designed dimensions of (b) 70 µm × 15 µm and (c) 50 µm × 15 µm. (d) SEM image of the fabricated BeCu probe array.

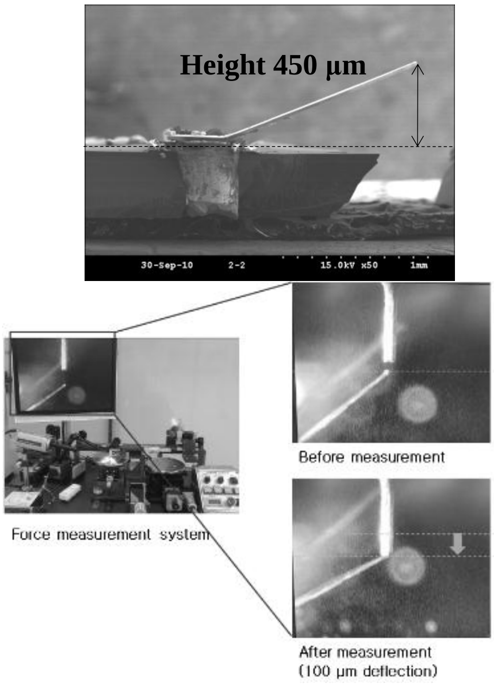


Figure 7: Force measurement system.

Table 1: Material properties of a BeCu sheet.

Properties	Values	Properties	Values
Composition	$Cu_{98}Be_{1.8}Co_{0.2}$	Hardness(DPH)	373-435
Density(ρ)	8.36g/cm^3	Resistivity	78.18×10^{-9}Ωm
Young's modulus(E)	13.5kg/mm^2	Specific heat capacity(c)	0.38J/g℃
Yield strength	112-138kg/mm^2	Melting temperature(T_m)	1080℃
Tensile strength	130-152kg/mm^2	Electrical conductivity(σ)	59.6 ×106 S/m
Heat of fusion (H_f)	130W · s/g	Thermal conductivity*(k)	401W/m℃

Table 2: Pad, probe, signal path, and contact resistance for Al and Au pads.

Resistance (Ω)		Pad resistance	Probe resistance	Signal path resistance	Contact resistance
Al pad	Before touchdown	2.1	5.04	9.07	1.93
	After touchdown			10.62	3.48
Au pad	Before touchdown	1.1	5.04	7.98	1.84
	After touchdown			8.24	2.10

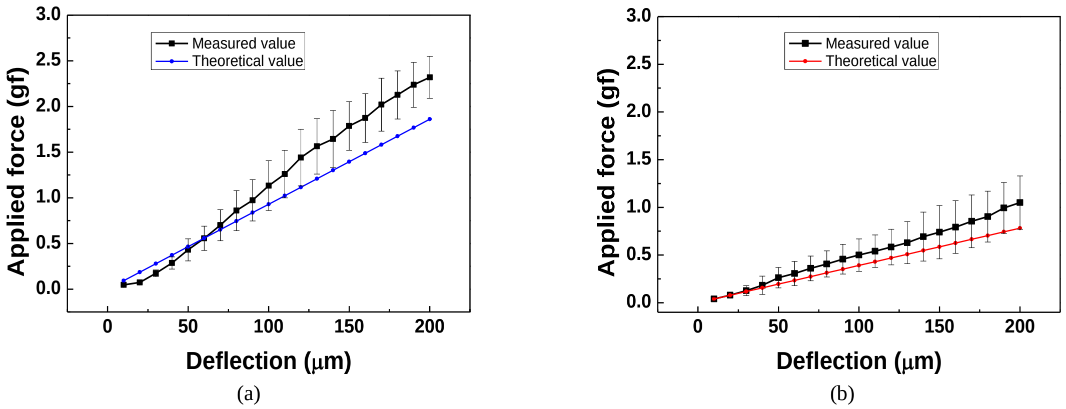


Figure 8: Contact force as a function of deflection for beam lengths of (a) 1.7 mm and (b) 2.1 mm.

4.2 Contact Force and Contact Resistance

To verify the array's usefulness in probe card applications, the contact force was measured as a function of deflection, as shown in Figure 7. The contact force was 1 gf/100 µm over the 1.7 mm length of the tip. The deflection of the end point of the cantilever exhibited a nearly linear relationship with the applied force, indicating that the cantilever undergoes elastic deformation in the linear region. When we measured the force, the effective length of the cantilever was smaller than the actual length because the measuring tip diameter (300 µm) was larger than the width of the tip end [15-18]. The true measuring point of the probe tip was 1.2 mm in length. Thus, the data were calculated using a length of 1.2 mm instead of 1.7 mm [17]. In the case of a probe tip point with a length of 2.1 mm, the data were also measured using a length of 1.6 mm. Figure 8 provides a plot of contact force as a function of deflection. We performed 10,000 touchdowns and observed no serious variations in contact force. Table 2 lists various resistance values for Al and Au pads. The contact resistance between the Al pad and the probe before touchdown was 1.93 ohm, and that between the Au pad and the probe was 1.84 ohm. The signal path resistance between the tip end and the via hole end point was 9.07 ohm with the Al pad and 7.98 ohm with the Au pad when the contact force was greater than 1 gf.

5. Conclusion

We developed a probe array fabricated from a BeCu metal sheet; the array costs much less to produce than conventional MEMS probe cards. The proposed probe array was fabricated using Joule heating and fusing of an etched BeCu beam under overcurrent conditions. The beams were annealed at 4 A for 7 min to achieve stress-free tip formation via Joule heating and then instantaneously fused with a current of 20 A. The contact force and contact resistance were measured to verify the mechanical and electrical properties of the arrays. Our results demonstrate that this array can be used in probe cards for sophisticated testing of semiconductor devices.

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