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KEK - P 93-165
SW 9409

KEK Preprint 93-165
December 1993
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Submitted to the IEEE Transaction on Nucl. Sci. Symposium, November 2 - 6, 1993, San Francisco, California, U.S.A.

National Laboratory for High Energy Physics, 1993

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Submitted to the IEEE Transaction on Nucl. Sci. Symposium,
November 2-6, 1993, San Francisco, California

Development of Novel Fabrication Techniques for a Silicon Micro-Vertex Detector Unit using the Flip-Chip Bonding Method

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Abstract

Full-size models of a detector unit for a silicon micro-vertex detector were built for the KEK B factory. The Flip-Chip Bonding (FCB) method using a new type anisotropic conductive film (ACF) was examined. The structure using the new type ACF and improved fabrication process provide a sufficient electrical connection and good reliability for the detector unit.

I. INTRODUCTION

The micro-vertex detector for the KEK B factory consists of three layers of double-sided, double-metal silicon microstrip detectors (DSSD) [1]. The detector element of the vertex detector, a detector unit, consists of four to six DSSDs daisy-chained together with silicon end boards at each end of the unit. CMOS preamplifier-analog memory VLSIs, a CMOS control VLSI, and other necessary electronic components [2], are mounted on both sides of the end boards. Fig. 1 shows the unit, which consists of four DSSDs. To obtain the necessary electrical connection to strips between the DSSDs and the silicon end boards, the wire bonding method, which has been used for single-sided silicon strip detectors, can be applied. The application of the wire bonding method to the DSSD, however, requires skilled hands and careful handling of the detector unit. In order to study the new assembly method for detector units using Flip-Chip Bonding (FCB) methods, several model detector units were built [3, 4]. We will report here on an FCB method using a new type anisotropic conductive film (ACF) and on other modified FCB methods.

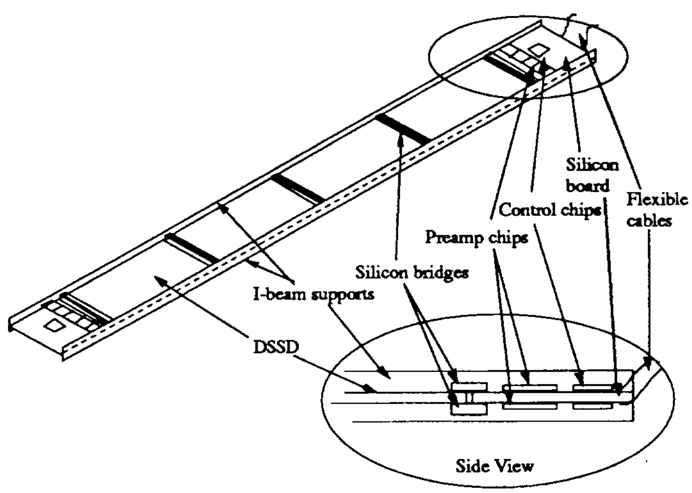


Fig. 1 Detector unit configuration.

II. FABRICATION PROCEDURE

The model detector unit consists of four dummy DSSDs (67 mm x 34 mm) and two silicon end boards (26 mm x 34 mm). On each side of the silicon end boards, five dummy preamplifier-analog memory chips and one dummy control chip are mounted. Each side of the dummy DSSD has 640 Al strips at a pitch of 50 μm. The size of the strip double bonding pads are 120 μm x 60 μm. They are arranged in double columns at a pitch of 100 μm on the DSSD. Au bumps are 100 μm x 40 μm and 10 μm high [3].

The DSSDs were first aligned with their neighbors using a guiding tool on an alignment bench equipped with vacuum chucks. A silicon bonding bridge (4.22 mm x 33.18 mm) with anisotropic conductive film (SONY chemical CP series; current type CP7131 and new type) on its bonding pads was mounted on the xyθ alignment head of a robot arm, aligned with the two DSSDs, and glued onto them. After connecting four DSSDs and two silicon end boards on one side, the unit was cured at 150°C for 20 s with a pressure of 12 g/pad (prior pressure 10 g/pad) on the silicon bonding bridges. In order to solve the problem of insufficient capability [4], the heater head has been changed from 0.5 mm thickness plate to block stainless steel. Fig. 2 shows both the heater head and the curing process. The dummy VLSI chips were mounted previously. On the other side, five bonding bridges and dummy chips were mounted in a similar way. Finally, the I-Beams (CFRP) were glued on to the long edges of the unit using an epoxy resin (EPOTEC 302-2) at room temperature.

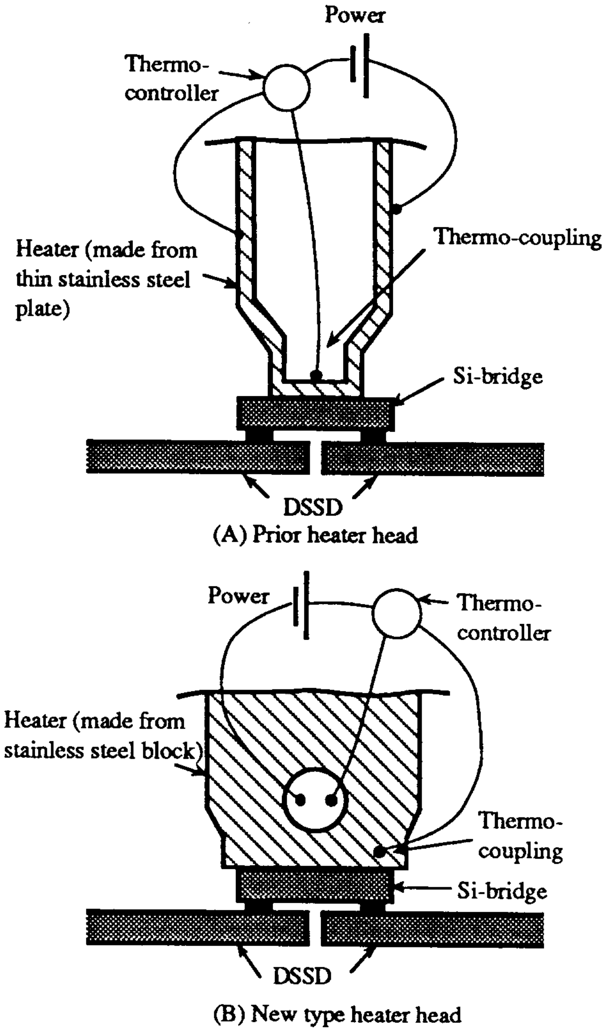


Fig. 2 Schematic diagram of the heater head and curing process.

III. PERFORMANCE WITH NEW ACF

The mechanical properties using the FCB method have been examined in a previous study (e.g. straightness, gravitional sag, and deformation by heat shock etc. [3, 4]).

A. Electrical Connection

The anisotropic conductive film used here is made of an epoxy glue (25 μm thick) which contains 5 μm dia. Au- and Ni-plated plastic balls. The nominal density of the balls was about 4100 balls/mm^2 in the current type and 16000 balls/mm^2 in the new type. The balls between the Au bumps were to provide an electrical connection between the facing bumps. The resistance of Au- and Ni-plating was assumed less than 100 mΩ/ball. The balls in the new type ACF were coated with a thin insulating layer. Fig. 3 shows a schematic cross section of the ball. Photo 1 shows an enlarged view of the bonded pads and balls. Photo 2 shows the distribution of balls within the new and current types. Cluster of balls is seen in the new type. The balls held between the faced bumps provided an electrical connection because the insulating layer was destroyed by the bumps, but unexpected connection with neighboring bumps was prevented, in spite of the high density.

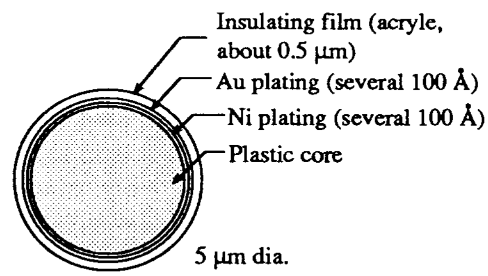


Fig. 3 Schematic cross section of the ball.

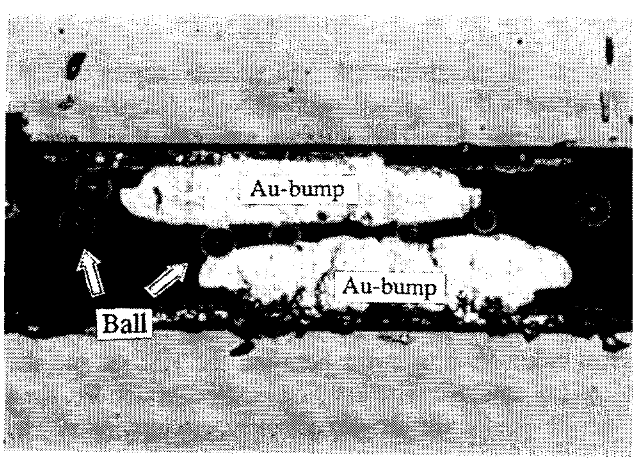
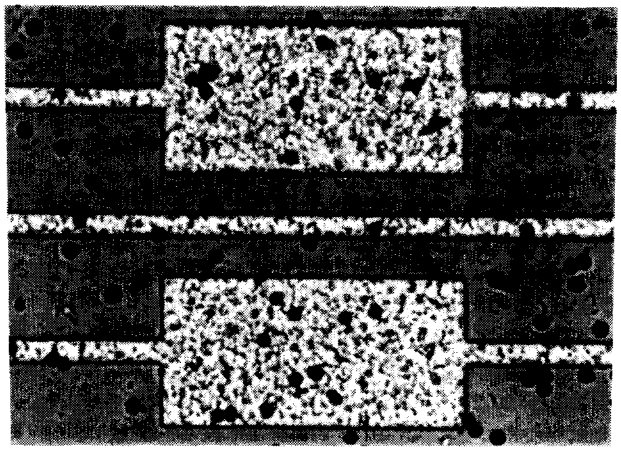
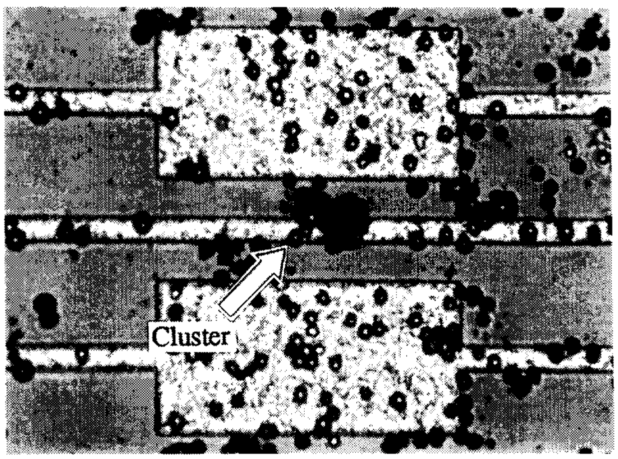


Photo 1 Enlarged view of the bonded pads and balls.



[A] Current type ACF.



[B] New type ACF.

Photo 2 Distribution of balls within ACF spreading over the pads.

The electrical connection failure rate between DSSDs was examined for special samples (8 samples for each type) with two DSSDs bonded using the single column bump bridge on one side. The assembly procedure was taken out as described in this report. To check the failure rate, open/short measurement was done on the 640 strips. Table 1 shows the calculated and measured electrical connection failure rate between DSSDs. The calculated failure rate was derived from the ACF ball density, the bonding pad area [100 μm x 40 μm bumps arranged in double columns (i.e. two pads per line) at a pitch of 100 μm] and the existence of cluster of balls at new type, using Poisson's distribution. Satisfactory electrical connection for the genuine detector units is expected on double column connection using the new type ACF. The source of the difference between the calculated and measured values would be the ball density variation (vender specification, maximum and minimum) within the ACF.

Table 1 Electrical connection failure

	New type	Current type
Ball density (balls/mm^2)	16000	4100
(Vender specification)	(not yet)	(+2600, -2100)
Calculated failure rate (%)		
double column	0.01	0.2
single column	1.6	4.7
Measured failure rate (%)		
single column	ave. 0.3	ave. 2.2

The contact resistance was measured about 1.0 Ω and was small enough compared to the strip resistance, and the isolation resistance between neighboring strips was measured at more than 500 MΩ for the new type. There were no problem with either.

B. Reliability Endurance

An accelerated high-temperature, high-humidity test (85°C / 85%, 500 hours) on model detector units in this study showed no significant increase in connection failure. The curing problem [4] which might affect reliability endurance has been resolved by changing the heater head to block stainless steel.

C. Radiation Effects

Radiation effects on the FCB method using ACF have been tested. To check the radiation effects on the electrical properties, the connection failure rate and the contact resistance were measured before and after γ-ray irradiation. Samples were fabricated in the same way as the connection failure rate special samples. Table 2 shows the results. No significant increase of failure rate was found. Non negligible increase of the contact resistance was seen, but the resistance did not depend on the irradiation dosage. Thus, this contact resistance increase was assumed to be caused by the condition of the probes.

Table 2 Radiation effect results; electrical properties

Sample No.	1	2	3	4	5	6
Dosage (rad)	200 k	200 k	1 M	1 M	5 M	5 M
Failure rate (%)						
Initial	0.63	0.16	0.16	0.00	0.16	0.16
After irradiation	0.63	0.16	0.16	0.00	0.16	0.16
Contact resistance (Ω, ave.)						
Initial	1.06	2.10	1.51	2.12	2.36	1.32
After irradiation	2.85	2.66	1.44	2.20	3.58	1.44

To check the radiation effects on the mechanical properties, tear off strength was measured. Horizontal force was applied to dummy LSI chips attached to silicon end boards, and tear off strength was measured. Table 3 shows the results. No significant influence was seen.

The effects of neutron irradiation will be measured in the future.

Table 3 Radiation effect results; tear off strength

Sample No.	A	B	C	D	E	F	G	H
Dosage (rad)	0	0	200k	200k	1M	1M	5M	5M
Strength (kgf)	9.8	5.5	18.2	7.5	4.9	12.8	17.0	8.5

(All samples the new ACF)

IV. Modified FCB Method

A. Without Au-Bump

Bonding without Au-bumps (one side with bumps, other side without bumps) using new the type ACF has been tried. Photo 4 shows the bonded pads and balls. Less than 1% connection failure rate was obtained.

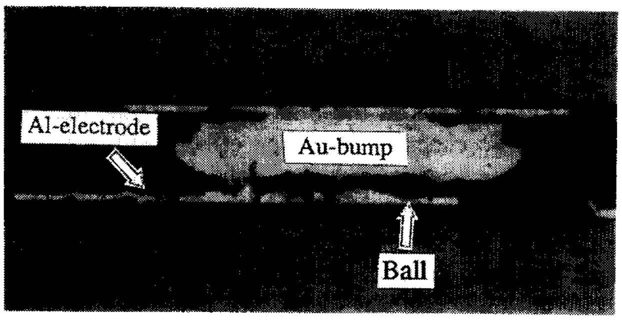


Photo 4 Enlarged view of the bonded pads and balls.

The no Au-bump process is beneficial and significant for the DSSD yield and processing time. This method is to be studied further.

B. Anodic Bonding

The anodic bonding technique was tried instead of ACF for bonding the DSSDs and the bridges. Photo 5 shows the bonded DSSDs and a glass bonding bridge (Pyrex). Fig. 4 shows the schematic cross section of the bonded DSSDs and the glass bridge in Photo 5. At elevated temperatures (yet below the softening point of Pyrex), the positive sodium ions in the glass become quite mobile and they are attracted to the negative electrode on the glass surface where they are neutralized. The more permanently bound negative ions in the glass are left, forming a space charge layer in the glass adjacent to the silicon surface. After the sodium ions have drifted toward the cathode, most of the potential drop in the glass occurs at the surface next to the silicon. The two substrate then act as a parallel plate capacitor with most of the potential being dropped across the several micron wide air gap between them. The resulting E-field between the surface serves to pull them into contact with a force of approximately 350 psi for E= 3E-6 V/cm. The extremely high fields transport oxygen out of the glass to bond with the silicon surface. Thus bonding has been completed [5]. The bonding process in this study was performed at 400°C and there was 600 V bias between the glass bridge and the Si substrate (DSSD).

The anodic bonding technique should have several advantages, such as easy alignment, higher mechanical strength, higher temperature endurance, no outgassing, no necessity of bumps, etc. The failure rate of the electrical connections, for all 640 strips, was measured about 10%. There may be many problems to be solved.

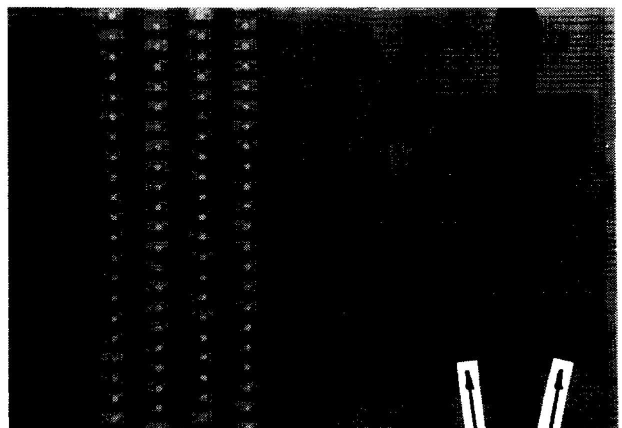


Photo 5 View of the bonded DSSDs and the glass bridge (Pyrex).

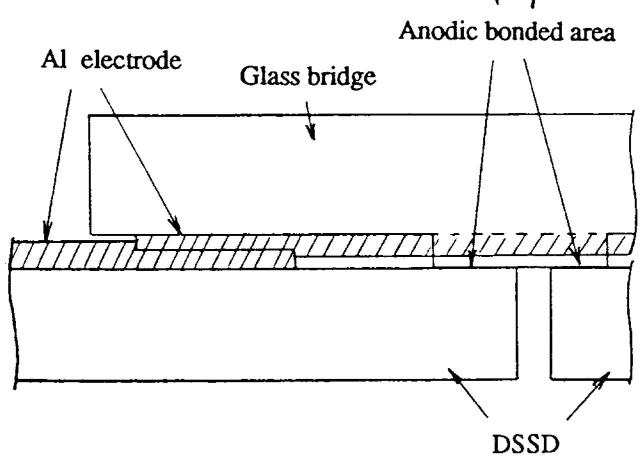


Fig. 4 Schematic cross section of Photo 5.

V. CONCLUSION

The FCB method using new the type anisotropic conductive film with an improved fabrication procedure was tried in the architecture for a vertex detector unit using DSSD. The architecture using the FCB method is to provide good mechanical performance for a detector unit in a silicon micro-vertex detector [3, 4]. The FCB method using the new type ACF and an improved fabrication process has provided sufficient electrical connection, satisfactory reliability and good radiation hardness.

The FCB method, assisted by the anisotropic conductive film, together with the use of the silicon end board, will provide flexibility in the line and pad layout and in turn in the design of readout VLSIs having the same thermal expansion coefficient [3, 4]. The FCB method has been made realistic by using the new type ACF.

The one side bump method was also tried successfully. This is to be studied further.

The anodic bonding technique was tried, but still has many problems to be solved in spite of its advantages.

ACKNOWLEDGMENT

The authors wish to thank Dr. P. Weilhammer, CERN/PPE and Dr. R. Horisberger, PSI, for providing us the necessary mask design for the dummy detector. This work was done as a part of detector R&D for the KEK B factory.

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