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Flip Chip Assembly for Cryogenics and Flexible Substrates

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Many elementary-particle and nuclear physics experiments are performed at cryogenic temperatures. As channels counts and sensor densities increase there is a growing need for flip-chip bonding as a method for forming interconnections. Given the disparate materials that are often involved, differential contraction of the bonded material stack as the system cools is a major concern. Flexible substrates are widely used in the construction of photon science and particle physics detectors. The ability to flip-chip bond flexible substrates to rigid parts or other flexible substrates can be enabling and is not a standard process. This is particularly true for science experiments, which often operate in extreme temperature or radiation environments.

I. Introduction

MANY elementary-particle and nuclear physics experiments are performed at temperatures below 200 mKelvin. Examples include the Enriched Xenon Observatory (EXO), Background Imaging of Cosmic Extragalactic Polarization (BICEP), and the Cryogenic Dark Mark Search (CDMS) projects. As channels counts and sensor densities increase there is a growing need for flip-chip bonding as a method for forming interconnections. Given the disparate materials that are often involved, differential contraction as the system cools is a major concern. Studies have been performed to determine the robustness of flip-chip-bonded silicon integrated circuit and sensor chip pairs under thermal cycling to temperatures below 1 Kelvin. Using Indium as the bump material provides a soft interface with modest ability to conform to stresses in a dominantly elastic manner.

Flexible substrates are widely used in the construction of photon science and particle physics detectors. The ability to flip-chip bond on flexible substrates or to connect rigid parts to other flexible substrates can be an enabling technology and is not a standard process. This is particularly true for science experiments, which often operate in extreme temperature or radiation environments. Procedures are being developed to fabricate conducting traces on flexible substrates with line-space features as small as 5 microns.

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II. Thermal-cycling Studies

To evaluate the compatibility of our in-house bumping process [1] for cryogenic operation we build a test device for cooling studies. After fabricating Indium bumps on a prototype ASIC and sensor, and flip-chip bonding them together, the hybrid chip was glued and wire-bonded to a PCB board and strong-back. The whole assembly was placed in a He3 refrigerator and cooled down to about 1K. The assembly was cycled between 1K and 4K several times before warming up to room temperature.

Fig. 1. Assembled board with a prototype chip with 50µm pitch bumps after temperature cycling to 1K.

As shown in figure 1, the prototype assembly did not exhibit any critical failure during the thermal-cycling. None of the interfaces: the Indium bumps connection, the glue between chip-board and board-strong-back showed signs of deterioration. After the thermal cycling, the module was successfully operated at room temperature, and offset and noise data was taken. Figure 2 shows the noise maps of the ASIC before and after the thermal-cycling; the two images are similar and only slight degradation at the top-right corner is observed.

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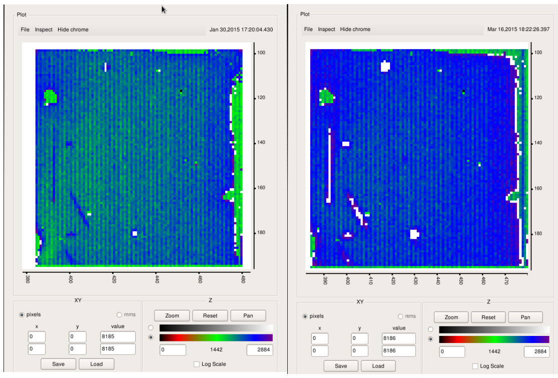


Fig. 2. Noise map of a bump-bonded assembly before (left) and after (right) thermal cycling to 1 Kelvin.

III. Flexible Substrates

For our flexible substrate studies we implemented an Electro-Cortico-Graphy (ECoG) like design intended to read-out rat's brain activity. One side of the traces would be connected to the electrodes placed directly on the cerebral cortex, and the other end would be connected to the electronics read-out.

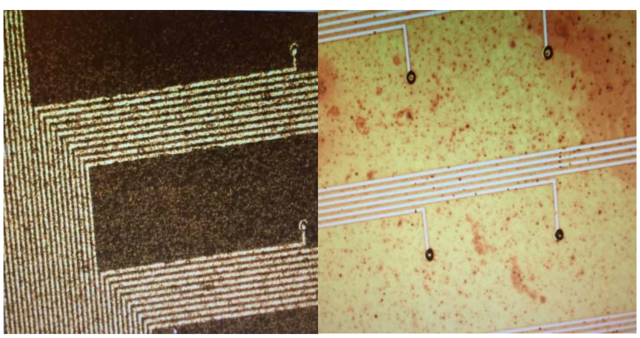


Fig. 3. : Picture of Al traces and In Bumps on 8µm thick Kapton (left) and 50µm thick Kapton (right).

The ECoG design consists of 10 µm wide Al traces with 20µm pitch. The thickness of the evaporated Al film for the traces was about 2500A. The design was defined by a lift-off process (see Figure 3). We fabricated this structure on Polyimide substrates with different thicknesses (3µm, 8µm and 50µm). In preparation for bump-bonding to the IC, Indium bumps were evaporated on both the ECoG flex and on the Si ASIC. The flexible substrate was mounted on a handle wafer to take advantage of standard semiconductor equipment as shown in Figure 4a). Further processing steps were identical to our in-house bumping of silicon devices.

The assembled flex/ASIC hybrid was successfully attached as shown in Figure 5. We plan to design a testing apparatus to verify the electrical functionality of the assembly. The electrical test is not trivial as the ASIC need to be operated and the electrodes on the other end of the flex cable need to be connected to the brain of a rodent or similar.

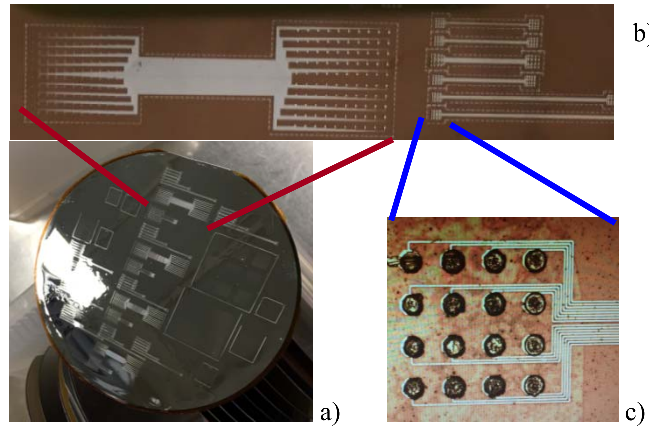


Fig. 4. a) Image of ECoG Al traces and In bumps views of the whole wafer; b) zoom-in of the traces; c) zoom-in of the electrodes.

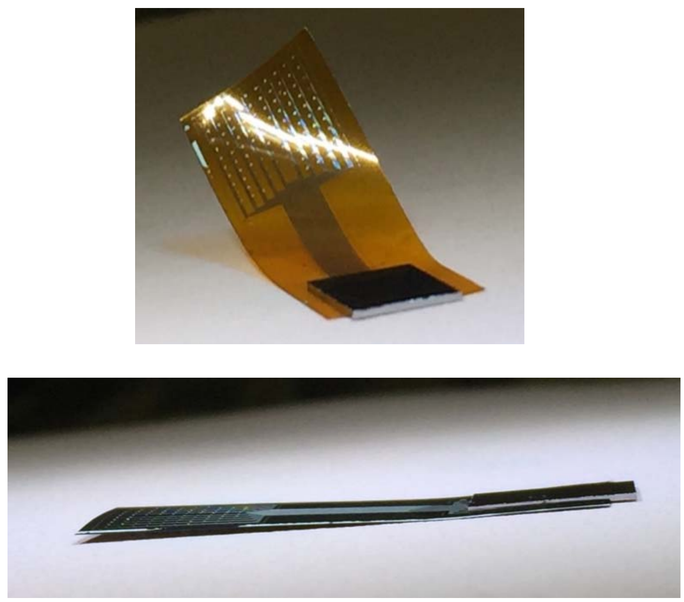


Fig. 5. Images of bump-bonded ASIC to 50µm thick Kapton flex eCoG (top image) and onto 8µm thick Kapton eCoG flex (bottom picture).

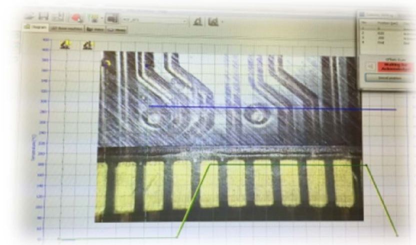
IV. Anisotropic Conductive Films

Anisotropic Conductive Films (ACF) are widely used in liquid crystal display manufacturing, mobile phones and CMOS camera modules electronics. We are considering their use for scientific interconnect problems.

We performed proof of concept studies by bonding two flex cables together and bonding a flex cable to a small rigid PCB. The use of ACF for bonding required two bonding steps compared to only one used in conventional bump-bonding process. First, the film is applied on one of the substrates to-be-bonded with heat (~ 80°C) and pressure (few N); then the second device is aligned and bonded with heat (~ 200°C) and force (~ 22N). Note that in the second step the amount of heat and force applied are substantially higher than that used in the first step.

ACF comes in several flavors depending on the pitch and size of the contacts and the material of the substrates. In our proof of concept we experimented with two variety of ACF (see figure 6).

a)



b)

c)

Fig. 6. Samples of ACF bump-bonding: a) Flex cable and PCB board bonded; b) Image from the bump-bonder with profile recipe of the alignment of the pads; c) two flex cables bonded.

The two kinds of ACF used to make these trials were: ACF CP-13341-18AA for flex to glass bonding [4] and the ACF CP-801AM-3545 for flex to PCB bonding. Dixerials America Corporation, San Jose, CA is the manufacturer of both products. We achieved electrical continuity using the first type of ACF for flex to glass material, further studies are under way to attain the same result with ACF for flex to PCB.

Conclusion

We showed that our in-house bump-bonded prototype camera chip is functional after being thermally cycled to cryogenic temperature. We fabricated Aluminum traces on flex substrates and bump-bonded one end to an IC. We also experimented with Anisotropic Conductive Films (ACF) to bond flexible substrates to rigid printed circuit board (PCB).

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