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Novel production method for large double-sided microstrip detectors of the CBM Silicon Tracking System at FAIR

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The silicon sensors of the Silicon Tracking System of the Compressed Baryonic Matter experiment at FAIR, GSI are connected to the read-out electronics by low mass flexible microcables due to tight material budget restrictions. The cable length of up to 50 cm and its flexible nature make detector module assembly one of the most critical parts in STS. A novel low mass, low capacitance multilayer copper microcable has been designed and produced to facilitate detector assembly. Furthermore, a novel detector production method based on high-density gold stud bump bonding of silicon die on microcable has been developed. We present the Cu microcable design, capacitance simulations and measurements together with the individual steps performed in the STS detector assembly.

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1. Introduction

Because of the very low material budget requirements for the Silicon Tracking System (STS) of the Compressed Baryonic Matter (CBM) experiment, the front-end electronics are located far from the sensitive sensor region and therefore are connected by low mass flex microcables with a length up to 50 cm. The primary assembly technology for STS is aluminum-aluminum TAB bonding based on aluminum polyimide microcables manufactured in Kharkov [2]. The Al-Al TAB bonding technology is well established and several dummy modules with varying cable lengths and sensor sizes have been produced [3]. However, there are two main disadvantages. First, the TAB bonding process is a highly manual process, requiring lots of man hours and skilled personnel. Second, there is only a single supplier for these cables located in the Ukraine.
Therefore a new double-layered copper polyimide microcable has been designed and produced. The microcable design, capacitance simulations and measurements are described in section 2. With this Cu microcable we developed a completely different assembly process based on solder paste printing on the cable and gold stud bump bonding on the die, a novel interconnection technique which might be of interest also for other future detectors systems. It combines low cost and high automation capability with good mechanical and electrical reliability. The individual production steps can be found in section 3.

2. Cu microcable design and production

The microcable plays an integral part in the detector module. Due to advanced Cu flex technologies and high yields a double-layered cable design is possible leading to a reduction of required cables by a factor of two. Figure 1 shows the developed cable schematically.

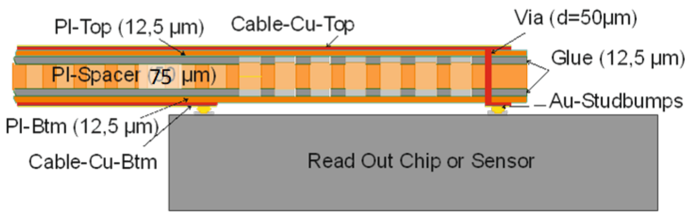


Figure 1: Schematic showing the developed two-layer Cu cable connected to a die. The top Cu layer is routed to the bottom side with vias. A meshed PI interposer with a fill factor of 30 % reduces the capacitance and adding only very little material budget.

The total thickness of the cable calculates to $\approx 115\,\mu$m. The copper line thickness is below $10\,\mu$m to minimize material budget. Still, due to the low radiation length of Cu the total material budget of $X/X_0 = 0.05\%$ is a bit higher compared to the aluminum cable ($X/X_0 = 0.03\%$), but still considerably below the sensor itself ($X/X_0 = 0.32\%$).
As the total noise in a detector channel depends strongly on the total capacitance connected to the input of the charge sensitive amplifier, the capacitance of the microcable has been measured on a needle prober. One Cu trace was set to high voltage while both neighboring lines and the four

lines directly beneath on the opposite side have been connected to GND, as shown schematically in figure 2. A capacitance of 8.8 pF was obtained for a 20 cm long cable, which calculates to 0.44 pF/cm.

FE simulations have been performed to further minimize the capacitance. The simulation results can be seen in figure 3. The cable capacitance is shown as a function of meshed interposer thickness for Cu trace widths of 18, 24, 30 and 36 μm. Based on this results, the trace width will be reduced from 36 μm to 24 μm and the thickness of the interposer will be increased from 50 μm to 75 μm for the next run of microcables.

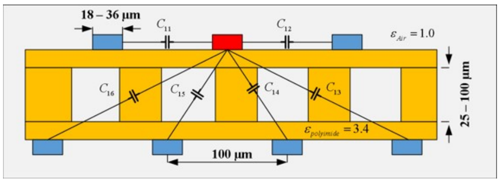


Figure 2: The setup for the capacitance measurements and simulations. One cable is put to high voltage while both neighboring lines and the four lines directly opposite are put to GND.

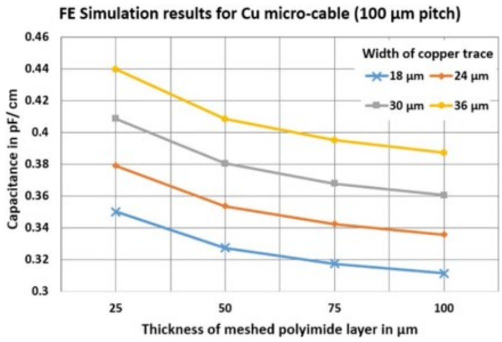


Figure 3: Results of the FE simulations showing cable capacitance over interposer thickness for different Cu trace widths.

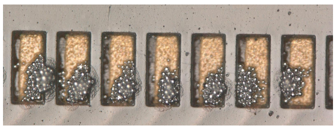
3. Detector module production based on Gold stud - solder paste bump bonding

3.1 Gold stud bumping

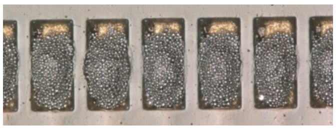
Gold stud bump bonding has been described and investigated previously at KIT [4, 5]. It is low cost, flexible and reliable. It is also fast, up to 20 bumps/s can be placed on the die. For STS, a gold wire diameter of 25 μm produces a Au stud of 60 μm diameter to make full use of the pad width. In a typical die-to-die interconnection, Au bumps can be placed on both dies which are subsequently bonded in a thermocompression process. However, Au bumping on the flex microcable has been investigated and shown to not lead to a reliable interconnection. The compressibility of the cable is too high for a proper energy transfer to the interconnection site.

3.2 Solder paste printing

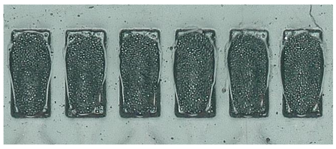
Solder pastes manufacturing has reached very fine granularity, with grain sizes of 2 μm to 8 μm for solder paste type 8. This makes solder paste printing also applicable for fine pitch applications in high energy physics such as CBM STS. We performed prints on the microcables with SAC305 solder pastes type 6 (5 μm to 15 μm), type 7 (2 μm to 11 μm) and type 8. The results are shown in figures 4a, 4b and 4c. Paste type 6 produces a non-uniform print with a low solder volume. Type 7 and 8 both lead to homogeneous prints with a sufficient solder volume. Based on this results, type 7 paste is used for STS, as type 8 has lower shelf life, higher cost and faster oxidation. The paste is printed on 140 μm $\times$ 50 μm bond pads on the microcable, as can be seen in figure 4b. For STS, a 40 μm thick stencil has been designed to allow for the concurrent printing of eight Cu microcables at once, ASIC as well as sensor side. After printing, the cables are directly reflown in a dedicated reflow oven to prevent oxidation and to make the cables storable. By this approach, the cables - similar to the dies - can be prepared in advance in an automated, low cost, fast way.



(a) Print result for type 6 solder paste showing insufficient solder volume and strong variation in shape.



(b) Type 7 solder paste print showing sufficient solder volume and good shape homogeneity.



(c) Type 8 solder paste print also showing sufficient solder volume and good shape homogeneity.

3.3 Thermocompression bonding

Bonding of ASIC on flex cable is performed under a Femto fineplacer flip chip machine with a high alignment accuracy of 0.5 μm [6]. Bond head as well as substrate plate are heated to 230 °C to minimize thermal stress induced by thermal mismatch. With a bond force of 40 N the stud balls are thermocompressed firmly into the solder paste printed on the microcable for about one minute to establish a strong mechanical connection.
The process leads to a solid interconnection for parameters ranging from 30 N to 40 N and 200 °C to 240 °C. Moreover, it works under ambient atmosphere, so no additional gas supplies such as nitrogen or formic acid are required. With dedicated jigs it should be possible to automatically bond at least 8 ASICs in one run in about ten minutes.
The sensor - microcable interconnection is more challenging due to the larger sensor size, the fact that several microcables have to be bonded to one solid structure and the double-sided nature of the sensor. This time, the cable has to be picked up while the sensor stays on a substrate plate. Therefore a customized bonding machine is developed in-house. It consists of four highly precise stepper motors, a two-camera optical system, force control, automated vacuum control, a heatable bond head and sensor plate and fixed bond head mechanics capable to handle microcables with a length up to 50 cm. The current status of the machine is shown in figure 5. Automation software is under development in parallel for a fully automated bonding process.

3.4 Underfill application

Underfill is needed for two main reasons. First, the mechanical strength of the connection has to be improved further to guarantee that the interconnections withstand the CBM lifetime fluence of $1 \times 10^{14}\,n_{eq}/cm^2$. Second, the low voltage cable has to be protected from the high bias voltage that is applied to the sensor edge. Bias voltages will reach more than ± 250 V by the end of lifetime to compensate for the radiation damage of the sensor. The small gap between sensor and cable of roughly 30 μm does not offer sufficient spark protection.

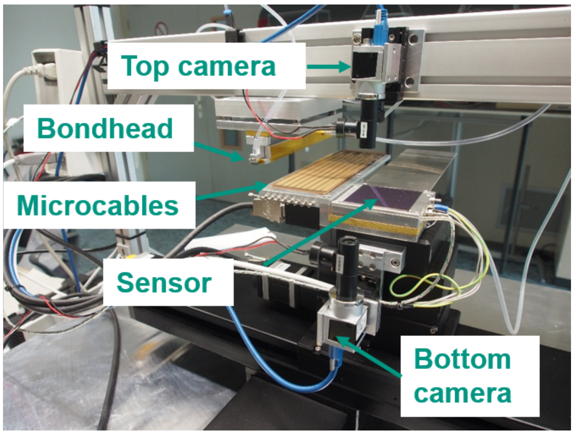


Figure 5: The in-house developed bonder machine currently under construction. It is designed specifically to handle the STS detector modules and will be used for a fully automated sensor-cable interconnection process.

4. Conclusion

An alternative assembly approach for the CBM STS has been developed. It is based on a specially designed low mass, low capacitance, double-layered copper microcable manufactured with highly advanced PCB technologies. FE simulations have been performed and cross-checked with real measurements to optimize the geometry of the microcable towards low capacitance.

Based on this cable, a novel die-on-flex production method for the STS detector modules has been developed. It uses Au stud bump bonding on the die side and solder paste printing on the flex microcable. A full process workflow has been established from the individual components to the complete module. It is geared towards a high degree of automation to enable a low cost, high speed assembly process.

It is expected that this interconnection technology proves as a suitable alternative to Al-Al TAB bonding for the CBM STS and thus might be of interest also for other future detector systems where high-density die on flex interconnections are required.

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