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Vacuum-compatible, ultra-low material budget Micro-Vertex Detector of the compressed baryonic matter experiment at FAIR

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ABSTRACT

The Compressed Baryonic Matter (CBM) Experiment is one of the core experiments of the future FAIR facility near Darmstadt (Germany). The fixed-target experiment will explore the phase diagram of strongly interacting matter in the regime of high net baryon densities with numerous probes, among them open charm mesons. The Micro Vertex Detector (MVD) will provide the secondary vertex resolution of ~50 μm along the beam axis, contribute to the background rejection in dielectron spectroscopy, and to the reconstruction of weak decays. The detector comprises four stations placed at 5, 10, 15, and 20 cm downstream the target and inside the target vacuum. The stations will be populated with highly granular CMOS Monolithic Active Pixel Sensors, which will feature a spatial resolution of <5 μm, a non-ionizing radiation tolerance of $>10^{13}$ n_{eq}/cm^2, an ionizing radiation tolerance of ~3 Mrad, and a readout speed of a few 10 μs/frame. This work introduces the MVD-PRESTO project, which aims at integrating a precursor of the second station of the CBM-MVD meeting the following requirements: material budget of $x/X_0 < 0.5\%$, vacuum compatibility, double-sided sensor integration on a Thermal Pyrolytic Graphite (TPG) carrier, and heat evacuation of about 350 mW/cm²/sensor with a temperature gradient of a few K/cm.

1. Introduction

The MVD of the fixed target Compressed Baryonic Matter Experiment [1] is to provide a high rate capability and an excellent secondary vertex resolution ~50 μm along the beam axis simultaneously, as required to identify open charm mesons by reconstructing their decay vertices. To avoid multiple scattering in vacuum windows between the target and the MVD, the detector will be operated inside the target vacuum. As shown in Fig. 1, the MVD will consist of four CMOS pixel detector stations [2] populated with sensors thinned to 50 μm. An ultra-light and vacuum-compatible cooling system is foreseen to evacuate the dissipated power of the sensors: The sensors of the MVD will be assembled on highly heat-conductive carriers clamped into liquid cooled heat sinks, which are mounted outside the detector acceptance, see Fig. 2. Steering, power and data links will be provided to the sensors via customized Flex Print Cables (FPCs).

The PREcursor of the Second sTatiOn (PRESTO) of the CBM-MVD is designed to validate this concept. It is to establish an assembly procedure, which guarantees vacuum compatible integration of the sensors on both sides of the carrier with a placing precision of better than 100 μm. Moreover, we study the feasibility of operating the sensors with an ultra-light FPC based on industrial technologies. PRESTO comprises 15 thinned MIMOSA-26 sensors [3,4], which were developed at the IPHC-Strasbourg. Nine of them are glued on the front and six on the back side of PRESTO. The sensors are wire bonded to a total of 10 FPCs, which provide the necessary bias lines and data links. PRESTO has the size of a quadrant of the MVD station #1 (see Fig. 1 for the numbering scheme). However, since MIMOSA-26 has a size of 21.5×13.8 mm² while the final sensor (MimoSIS) will presumably have a size of about 30×13 mm², its complexity is equivalent to the one of station #2, see [7]. The sensors and FPCs of PRESTO were integrated on a 380 μm thin carrier of the highly heat conductive Thermal Pyrolytic Graphite TPG [5]. This material will be used for the two downstream stations of the final MVD while the two upstream stations will rely on CVD diamond [6] carrier.

2. PRESTO assembly

In the following, selected aspects and results of the PRESTO

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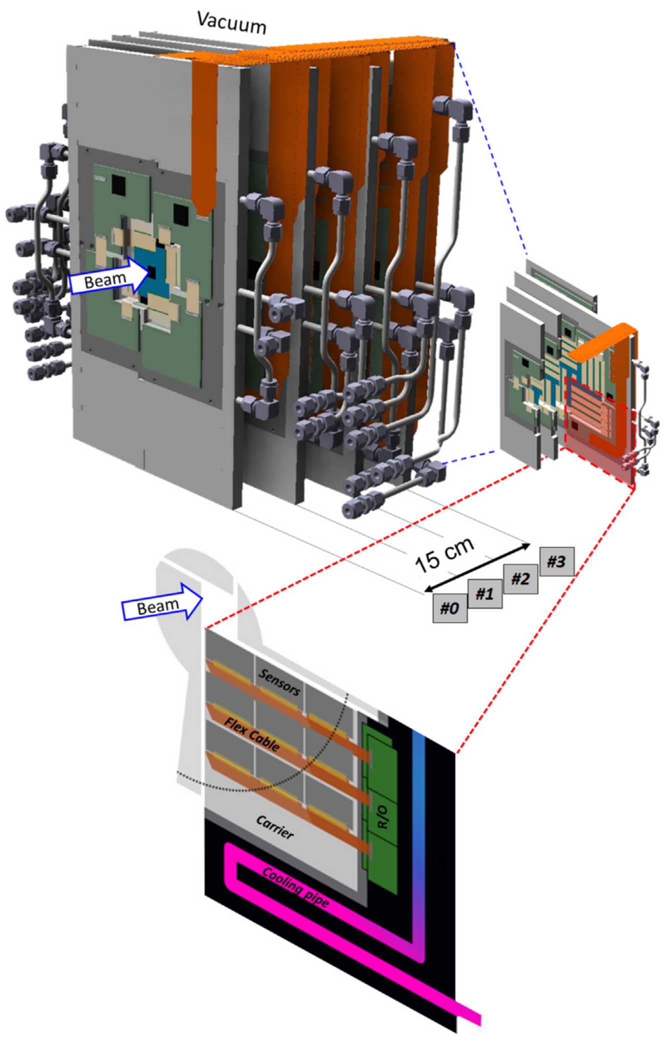

Fig. 1. Visualization of the Micro-Vertex Detector of the CBM experiment. The PRESTO size corresponds to a quadrant of the MVD station #1 and employs 9 MIMOSA-26 sensors on one side and 6 on the other side, respectively. The TPG carrier is clamped into an aluminum heat sink that holds also passive *R*/*O* electronics (DC filters and impedance matching).

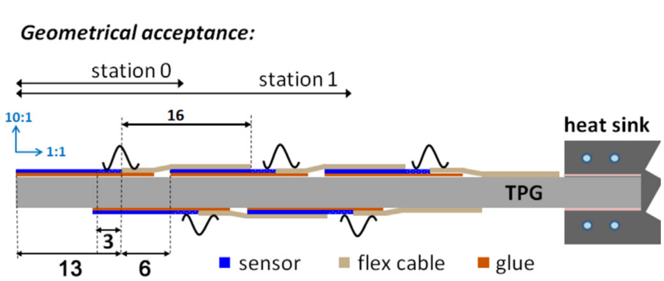

Fig. 2. Simplified cross-sectional view of the PRESTO module. Note, *X* and *Y* axes feature different scales.

assembly are presented and discussed w.r.t. their relevance for the final MVD.

2.1. Sensors and sensor quality assessment

The MIMOSA-26 sensors host 1152 columns with 576 pixels of $18.4 \times 18.4\ \mu m^2$ pitch each. The chip is read out by a column parallel rolling shutter within 115.2 μs. The data is discriminated and sparsified on-chip, and sent out via two 80 Mbit/s digital data links based on the LVDS standard. Slow control is done by means of a JTAG interface. The radiation tolerance of the chip is >150 krad and $>10^{13}\ n_{eq}/cm^2$, its power consumption is 750 mW and thus a factor of more than two higher than expected for the sensor of the final MVD. Despite these sensors do not meet the requirements of the MVD with respect to the radiation tolerance and readout time, they provide the opportunity to probe key aspects of the sensor integration. Due to its size and thickness of 50 μm, the device is perfectly suited for integration studies including questions of handling and bonding of such ultra-thin and hence curved sensors.

The total yield of MIMOSA-26 after production, dicing and thinning amounts to 60–70%. It is therefore mandatory to test the sensors prior to integrating them. The necessary probe test procedures for the 50 μm thin sensors were established within the PRESTO project. The tests were performed with a Suss-Microtech PA-200 probe bench and a standard industrial probe card hosting 65 tungsten needles with a minimum pitch of 120 μm. The sensors were held by a chuck adapter with micro-vacuum channels. They were contacted with the needles and their signals were routed through the probe card to a readout system based on TRBv3 [9]. The probe tests included testing the standard operation modes of the sensor and measuring its fixed pattern and temporal noise by the means of a transfer function scan. The temporal noise measured with the probe test setup was found to exceed the known noise of MIMOSA-26 by a factor of 2–3 in average. This effect can be tolerated for the selection of working sensors. It is caused by noise, which is picked up by the long and unprotected lines used for steering and powering the sensor and hereafter injected to it via a well identified, vulnerable node. This issue is specific to MIMOSA-26 and has already been eliminated in consecutive sensor versions.

It was observed that an over-drive of about 100 μm was needed for achieving a good contact between the needle card and the sensors. This is beyond the limits of standard tungsten test cards. Therefore, the needles had to be routinely re-aligned after testing ~50 sensors. The observed yield was of about 65% which is in agreement with expectations for this type of sensors.

2.2. Custom-made adhesive

An "ideal" adhesive for the integration of the sensors onto their supports should be easy to dispense in a thin and uniform layer (low viscosity preferred), radiation hard, low out-gassing and flexible within the temperature range of −20 °C (operation) and +20 °C (assembly), to compensate for the thermal expansion mismatches between the sensor and their support material. Since no commercial product could be found which meets these requirements, a custom-made, two compound adhesive (working name RAL-247) was manufactured at the Rutherford Appleton Laboratory (RAL), Composites and Materials Testing Group, UK [10]. The glue features a glass temperature of −45 °C, a viscosity of below 100 mPa s and a curing time of 48 h at +50 °C. To investigate its radiation hardness, RAL-247 samples were irradiated with X-rays to 100 Mrad and exposed to a proton dose of about $10^{15}\ n_{eq}/cm^2$. The irradiated samples were sent to RAL for further Dynamic Mechanical Analysis tests, which revealed no significant change of properties that confirms the expected radiation hardness in the range of the radiation doses and temperatures expected at the MVD.

2.3. Heat sink

In order to dim the leakage currents and the shot noise found in irradiated sensors, the MVD will be operated at about −20 °C. The material budget of the related cooling system is minimized by integrating the sensors on a thin and highly heat conductive carrier, which drives the dissipated power towards actively liquid

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