Available on CMS information server **CMS NOTE 2003-016**

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

Development technology of manufactures the ceramic PCBs for Preshower detector of the CMS experiment

A.Sirunyan, F.Adamyan, G.Baiatian, H.Hakobyan
YerPhI, Yerevan , Armenia

A.Khaletzkij, B.Harutunyan
MARS factory, Yerevan, Armenia

M.Asatryan
YerTRI, Yerevan, Armenia

Abstract

In the framework of the development of the CMS preshower, the Yerevan group has put emphasis on the design and prototyping of a Printed Circuit Board (PCB) on a ceramic substrate. After an initial tuning phase, the quality of the product (the adherence of metallic pastes, the contrast and resistivity of the metallic lines and the precision of the mechanical cutting) has become satisfactory. The ceramic supports produced in Yerevan by the Yerevan Physics Institute in collaboration with the MARS factory and the Yerevan Telecommunication Research Institute are currently used for preshower prototypes. This report describes in detail the R&D on the technology required to manufacture these ceramic supports for large-scale production (4500 pieces).

1 Introduction

The preshower detector is a part of the endcap electromagnetic calorimeter of the CMS experiment [1]. It consists of 4300 identical modules, each containing a 1.9 mm-pitch silicon strip sensor of 63x63 mm^2 [2, 3]. Fig.1 shows the layout of such a module. The silicon sensor and the electronics hybrid, which include the front-end readout electronics, are mounted on a ceramic Printed Circuit Board [4], which provides the reverse bias voltage to the back plane of the sensor. The ceramic is composed of alumina ($Al_2 O_3$) and has been selected primarily because of its excellent thermal conductivity and its flatness. The silicon sensor is glued to the ceramic and the heat generated in the sensor is removed through the substrate. The dimensions of the ceramic plates are face 93.0 ± 0.1mm in the direction parallel to the strips, 62.5 ± 0.1mm in the perpendicular direction, and 0.63 ± 0.05mm in thickness.

This report is organized as follows: Section 2 describes the thick film technology used to deposit metallic pastes on the ceramics substrate by a silk-screen printing method, and the subsequent firing at high temperature. In section 3 the technology of the mechanical cutting and drilling of the ceramic plates with a diamond disc is presented. Finally, the potentiality for mass production is discussed in section 4.

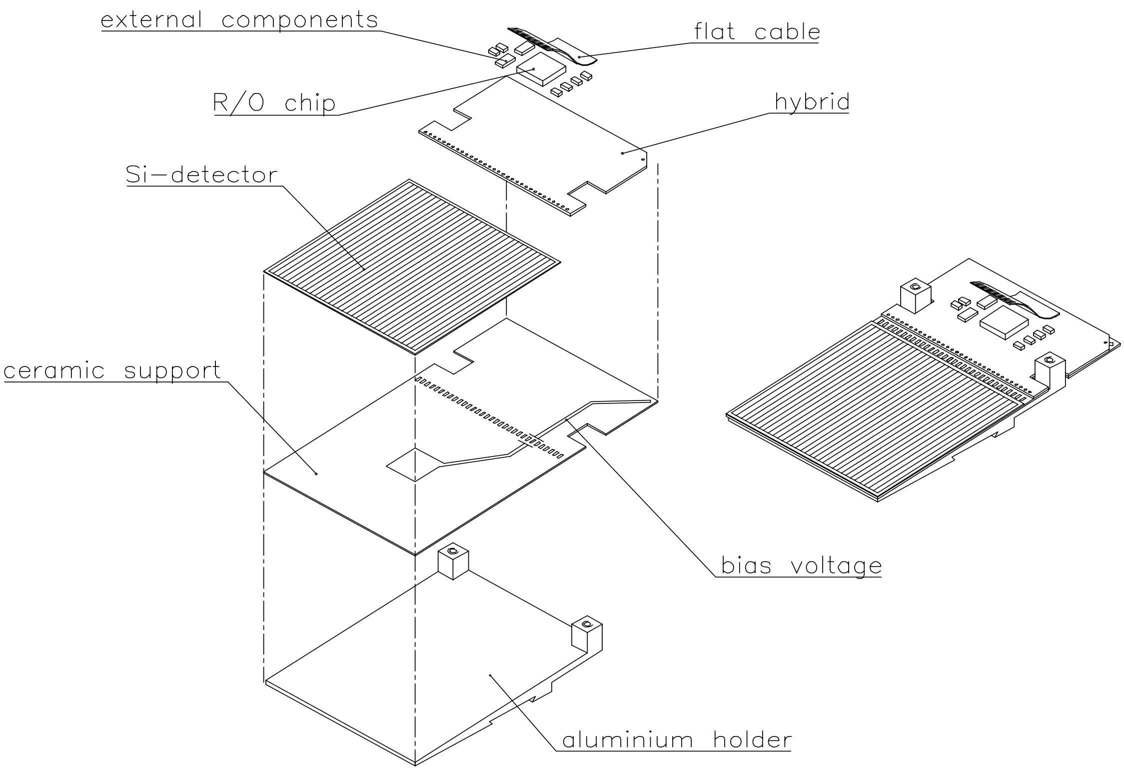

Figure 1: Endcap Preshower detector module

2 The development of thick film technology for ceramic PCBs using silk printing of metallic pastes

During the past years, YerPhI, in cooperation with personnel at the MARS factory, has developed a thick film PCB technology with a silk-screen printing method using various metallic (Au, Ag, Al, Au/Pt) and dielectric pastes, followed by firing at high temperature (650°- 900°C). The high temperature firing takes place in a belt furnace (Simon-Carves Ltd., England) located in the MARS factory (Fig.2). The main technical data of the furnace setup are as follows: there are five zones, the maximum temperature is 1050°C, the belt width is 230 mm and the belt speed is between 76 and 457mm/min. For the process to be successful, the main necessity is to control two parameters: the furnace airflow and the firing temperature profile. The firing process is performed in air. A good airflow (oxidizing atmosphere) during heat up is needed to guarantee the burnout of the organic vehicles of the metallic paste. The firing profile is controlled by the belt speed. The typical total time of firing is about 45 minutes: 18 minutes to go from room temperature to the peak temperature, about 10 minutes at peak temperature, followed by 18 minutes cooling to room temperature. Ten minutes was found to be the optimum time for staying at peak temperature.

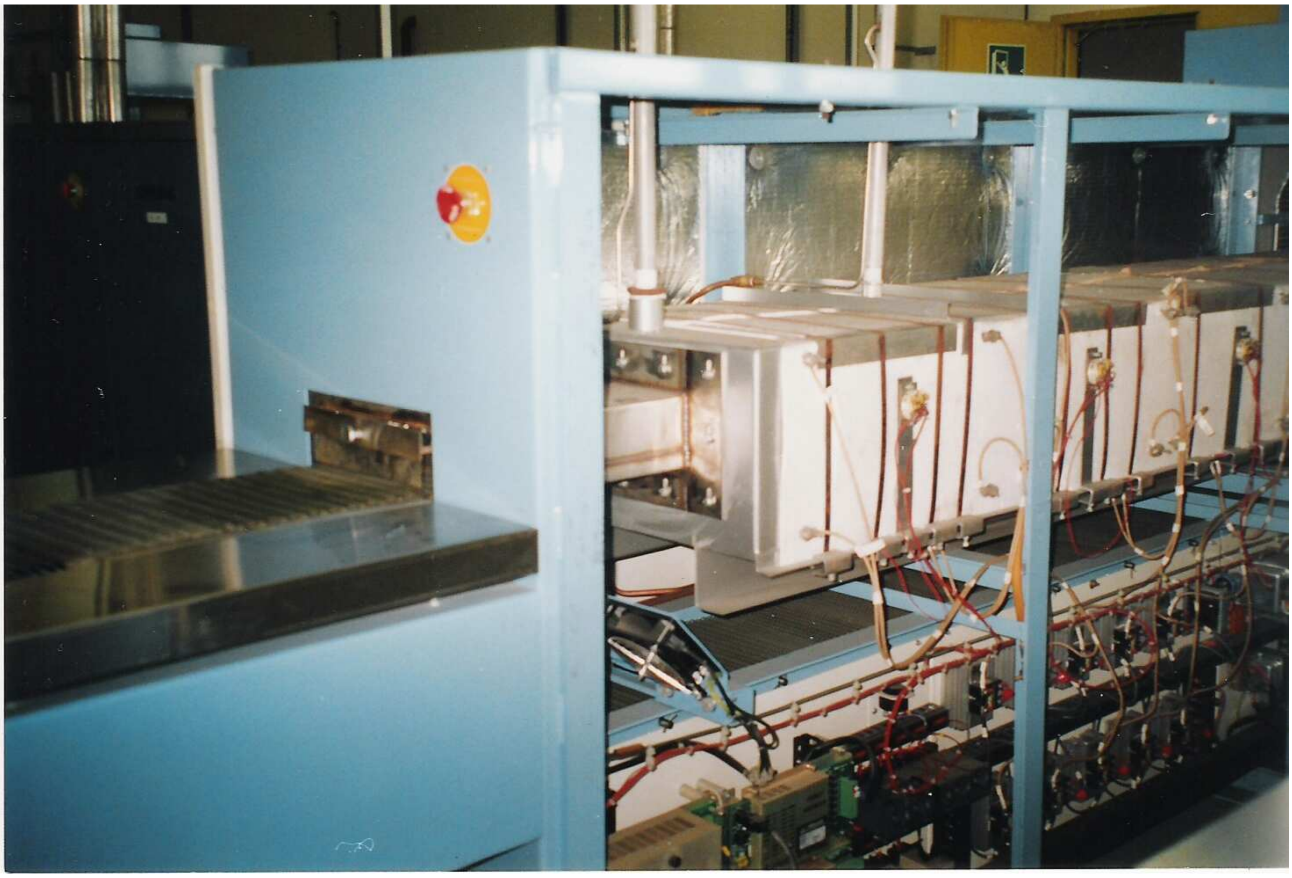

Figure 2: General view of the belt furnace at the MARS factory

2.1 The choice of the pastes and technology of their deposition on the alumina substrate

The choice of the pastes depends on their application (either conductor or dielectric in multilayer systems). In general, we used the pastes of two companies: DuPont Photomasks, Inc. and Electro-Science Laboratories, Inc.

In the initial design of the preshower module, the silicon sensor was glued and wire-bonded to pads located on the upper side of the ceramic. The bias voltage was provided on the back plane of the silicon sensor via a special line. The under side of the ceramic contained a large ground plane, insulated from the mechanical support and connected to the electronics by soldering. Therefore a three layer ceramic PCB was manufactured using two different metallic pastes (Au, Ag-Pt) and one dielectric, all fired at high temperature (850° - 900°C).

The bonding layer used a gold paste (ESL 8881B), the ground layer a silver paste (DuPont QS171) and the insulation layer a dielectric paste (DuPont QM42). These pastes are known to have a good oxidation resistance. They were deposited on ceramic substrates by silk-screen printing. The technology used for the material deposition is detailed in Ref. [4]. The typical fired thickness was 8μm for the Au-layer, 12μm for the Ag-layer and 18μm for the dielectric. A series of 70 PCBs were manufactured and delivered to CERN. Tests of bonding and soldering on this ceramics gave good results.

At LHC, the dominant component for the activation of the preshower detector comes from low energy neutrons [3]. Some ceramic PCBs were therefore irradiated with neutrons at the Dubna Reactor (Russia) [5]. The irradiation test showed, and it was confirmed by computations [3], that it is necessary to greatly reduce the amount of silver (silver has a metastable excited isotope with a half-life of 255 days that results in high long-term activity). The layout of the ceramic PCB therefore had to be modified to minimize the amount of silver.

Taking this problem into account, we developed another technology: a special aluminum conductor (ESL 2591) is deposited on the under side of the ceramic, and fired at a relatively low temperature (630°- 670° C). The products of Al activation decay very fast, however it is not possible to solder to aluminum and it was necessary to add a small overlap area consisting of a strip made of a special silver–paste (ESL 9910C) co-fired at low temperature. In addition it was necessary to use a different polymer (ESL 240SB) as insulator. The other side of the ceramic, with the gold deposition, remained the same as in the original design.

The process was as follows: first the aluminum paste (ESL 2591) was printed and dried, then the small silver strip (ESL 9910-C) was printed overlapping the aluminum. Then both were co-fired in a 30 minutes cycle to a peak temperature slightly above 650° C. Because aluminum oxidizes, it is important to go only slightly above the temperature of aluminum fusion to obtain a good conductivity. We determined the optimum temperature empirically by making systematic tests, increasing the peak temperature in steps of 10ºC . Afterwards we measured the resulting aluminum resistivity, which should be around 30 nΩm . Our investigations showed that the optimum firing temperature is T_{max} = 660°C . Prototypes (~ 30 pieces) were produced with this technique and delivered to CERN. Tests of bonding and soldering on these pieces gave good results.

Recent results with the custom electronics mounted have shown that the ground layer on the under side of the ceramics is probably not necessary. Also the size of the bias contact can be reduced to minimize the amount of gold. The present design is shown in Fig. 3. For this version bondable and solderable Pt/Au paste (ESL 5837) was used. Prototypes of this design (~ 100 pieces) have been produced at the MARS factory and delivered to CERN. They are being thoroughly tested, as the final production design.

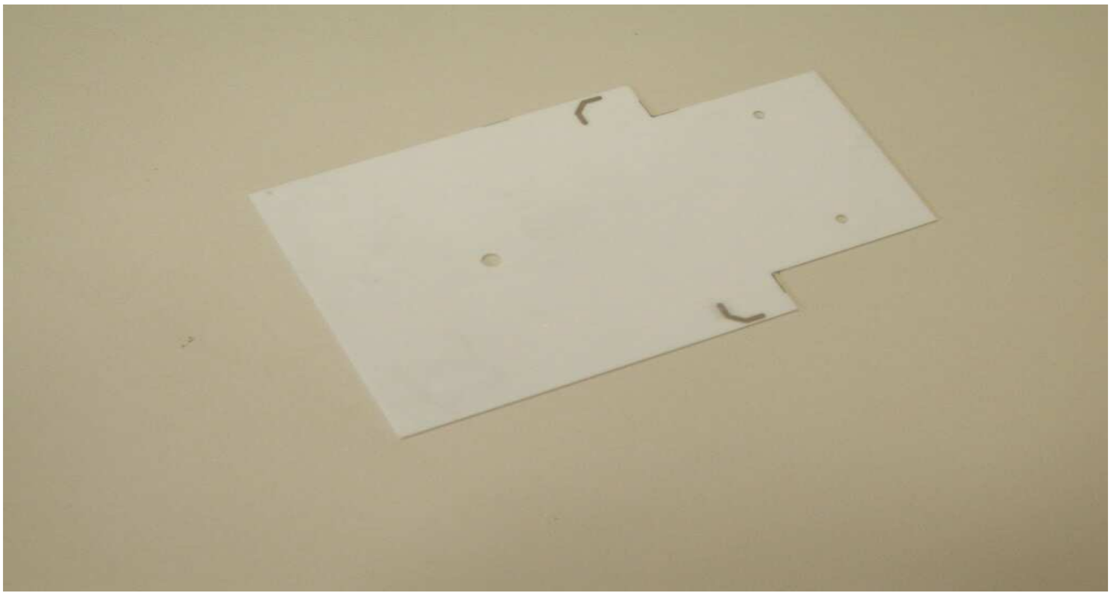

Figure 3: General view of the ceramic plate

3 Mechanical cutting and drilling of the ceramic plate with diamond disc

YerPhI in cooperation with Yerevan Telecommunication Research Institute has developed a technique to cut the ceramic plates with a diamond disc (0.35 mm thickness, 75 mm diameter) using a semi-automatic unit. The machine (Fig.4) has a rotating axis and a table moving in two orthogonal directions. The depth of the cutting is controlled automatically. The tolerance of cutting is ± 0.1mm.

Figure 4: Semiautomatic tool with diamond disc

The cutting rate is 1mm/sec, allowing production of four plates per hour. The shape of a ceramic plate (fig.3) contains reentrant right angles. It is not possible to perform such a cut with the large 75mm disk without leaving a small amount of extra material in the corner as illustrated in Fig. 5.

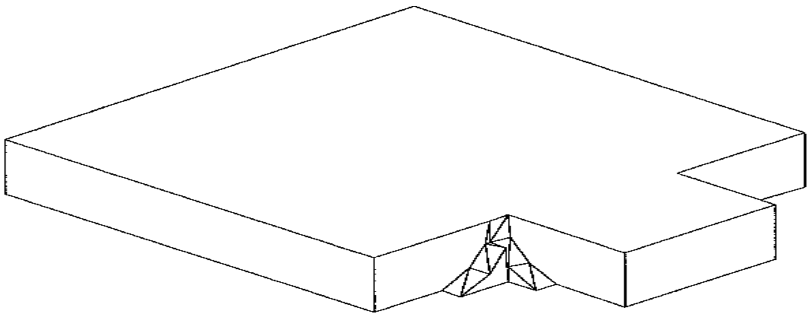

Figure 5: Remnant extra material after cutting the plate

For machining the internal right angles, a new tool with a 7-mm thick diamond disc was developed and used to mechanically remove the extra material. Moving the plate in two orthogonal directions along the right angles performs this removal and corrects the cutting to the right angle.
It is also necessary to make holes with 2 and 3mm diameters in the ceramic plates. For this purpose, another tool with a diamond drill was developed and manufactured, allowing these holes to be made efficiently.
The recent prototype runs of 100 ceramic PCBs were all cut using these new tool sets.

4 Mass production of ceramic PCB and quality control

Based on the experience in manufacturing prototypes of ceramic PCBs at the MARS factory, it is estimated that a production capacity of 500 pieces per month can be achieved.
After metal deposition, the ceramic plates will be transferred to the Yerevan Telecommunication Research Institute for cutting with the diamond disc and for holes drilling.
Based on the experience with prototypes a rate of ~ 400 plates per month is expected.
Finally, the ceramic plates will be brought to the Yerevan Physics Institute for machining the reentrant angles. The capacity for this operation is 600 units per month.
All ceramic PCBs will be tested at the Yerevan Physics Institute. The quality control includes visual inspection, dimensional measurements and tests of electrical parameters. The results will be transferred to a central database at CERN .
In summary, it is estimated that the mass production of 4500 PCBs will take about 12 months.

5 Acknowledgements

The authors would like to express their gratitude to Dr.Philippe Bloch for the interest and support of this work, as well as for proof-reading the manuscript, and also to Dr. Anna Elliott-Peisert from CERN for useful discussions regarding the manufacturing the ceramic PCBs. We would like to thank Nikolai Zamiatin from JINR-Dubna for his help for the irradiation of the ceramic PCBs with neutrons and the tests of their activation.

This report is a summary of work performed by the research group of YerPhI in cooperation with MARS factory and Yerevan Telecommunication Research Institute and was supported by the INTAS grant (INTAS-CERN-2000-908) and by NFSAT grant (NFSAT PH 061-02/ CRDF 12007).

References

1. Compact Muon Solenoid. Technical proposal. CERN/LHCC 94-38.
2. The Electromagnetic Calorimeter Project, CMS TDR-4, CERN/LHCC 97-33.
3. CMS ECAL EDR-4, vol.2: ECAL Preshower, 2000-054.
4. A Sirunyan. Manufacture of prototypes of the ceramic PCBs for Preshower detector at YerPhI. Preprint YERPHI – 1555(4), 2000.
5. A.Cheplakov et al., Radiation hardness of GaAs preamplifiers for liquid argon calorimeter at LHC, MPI-PhE/96-15.