Research into high thermal conductivity materials related to the upgrade of the CMS tracker

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Introduction

This document summarizes a market survey of high thermal conductivity materials for the upgrade of the CMS tracker. The first part of that paper considers structural materials that are light weight and that could be manufactured into thin sheets. The sheets are to be used as a support structure in the CMS Pixel detector where there is a need for efficient heat transfer between the cooling pipes and the silicon wafers. The second part deals with high performance adhesives to glue the sheets to the cooling pipes with the best conductivity possible. Mainly three types of structural materials are considered: carbon fiber materials, thermal pyrolytic graphite (TPG) and diamond. It is noted that the first two can have a highly anisotropic thermal conductivity.

Carbon fibers and graphite fibers materials have extremely thin fibers of about 0.005–0.010 mm in diameter. They are highly conductive, but only along these fibers. Also, they lose conductivity when mixed with epoxy. In the material, the fibers can be oriented in one, two or all three directions. Depending on the required performance, different ratios of fibers along each axis can be chosen.

TPG is a unique form of graphite manufactured by decomposition of a hydrocarbon gas at very high temperature in a vacuum furnace. Its layered structure is responsible for the material being highly anisotropic. Thus, TPG has high thermal conductivity along the horizontal plane but very low along the vertical plane. Some experiments done at Fermilab revealed that the TPG substrate needs to be stiffened due to delamination and strengthened because parts got damaged easily. They used CFRP encapsulation to avoid too much mass and for good conductivity. The material was successfully used for Fermilab MTest Pixel Detector and the Phenix Pixel Detector. Finite Element Analysis was made with this material for the CMS FPIX Detector. The results were quite satisfying since the temperature differences across each module were within 5 °C. For more details on the experiments, refer to this link: http://postema.web.cern.ch/postema/CO2_cooling/Fermilab/TPG_090209_f.pdf

Diamond is known for its high thermal conductivity. Several methods exist to produce diamond synthetically, such as Chemical Vapour Deposition (CVD) and High-Pressure High-Temperature (HPHT) synthesis. Diamond offers conductivity in all directions but the limiting factor is the shaping.

Structural Materials			
Product	**Company**	**Thermal conductivity a,b,c axis [W/mK]**	**Additional information**
PYROID® HT pyrolytic graphite	Minteq	1700[a], 7[c]	Sheets up to 30 cm^2 and thickness from 0.25 to 1.3 mm
TPG Thermal management material	Adv. Ceramics/Momentive	1500[a,b], <20[c]	Layered structur. Easily machined, provided as plates or as final shapes. Thickness from less than 0.25 mm to over 5 mm
TC1050 Thermal management material	Adv. Ceramics/Momentive		TPG core encapsulated in various structural materials: Aluminum, copper, kovar, tungsten/copper, carbon
Pyrolytic Graphite	Adv. Ceramics/Momentive	300[a,b], 3.5 [c]	Chemically inert, high purity, impermeable, self-lubricating, non-
TCPG-plate	Optigraph	1700/100	150 mm x 30 mm x 0.5(+1) mm, other sizes on request
TCPG-film	Optigraph	1900	Thickness 50-500 µm, size on request
PGS Graphite Sheets	Panasonic	700-1600	
ECOPHIT	SGL Group	250-500	
DIAFILM TM100: CVD Diamond	Element 6	>1000	10x10 mm, 0.25 mm thick
DIAFILM TM150: CVD Diamond	Element 6	>1500	10x10 mm, 0.25 mm thick
DIAFILM TM180: CVD Diamond	Element 6	1800	10x10 mm, 0.25 mm thick
POCO HTC	POCO	245 (out of plane), 70 (in plane)	Eventual fillers: copper, polymer or additional carbon. Wetted by liquid nitrogen, methanol, Fluorinert™
POCO Foam	POCO	135 (out of plane), 45 (in plane)	Structure of highly aligned graphitic ligaments within the foam's cell walls.
K Foam Grade D	KOPPERS	110 (z-dir)	
K Foam Grade L1a	KOPPERS	55 (z-dir)	
K Foam Grade L1	KOPPERS	55 (z-dir)	
Aluminum Nitride Ceramics (AlN)	Sumitomo	95	410 x 95 x 0.6mm sheets
CVD Diamond	Sumitomo	>1000	

Adhesives				
Product	**Company**	**Thermal conductivity [W/mK]**	**Density [g/cc]**	**Additional information**
3-6652 Thermally Conductive Encapsulant	Dow Corning	1.9	2.7	Two-Part. Low modulus; thixotropic; good thermal conductivity
3-6655 Thermally Conductive Encapsulant	Dow Corning	1.8	2.7	Two-part. Low viscosity; soft; excellent thermal conductivity; UL 94 V-0.
SE4490CV Thermally Conductive Compound	Dow Corning	1.7	2.62	One-Part. Non-curing, thermally conductive silicone paste
TC-5021 Thermally Conductive Compound	Dow Corning	3.3	3.5	One-part. Non-curing, thermally conductive silicone paste
TC-5022 Thermally Conductive Compound	Dow Corning	4	3.23	One-part. Non-curing, thermally conductive silicone paste
XB 2731	Ciba Aratherm™	3		
XB 2730	Ciba Aratherm™	2.3		
XB 2721 (LMB 5665)	Ciba Aratherm™	2		
MAXIGLOW™ 501/502	Sunray scientific	5	1.77	Ag, Au.
Pelco High Performance Silver Paste. PELCO® 16047	TedPella	9.1	2.3	Ag (20 um flakes). Requires a 2 hour cure at 93°C (200 °F) to achieve stated high conductivity
Silver Conductive Epoxy, H2OE Epo-Tek®	TedPella	2.5		Ag (20 um flakes)
Loctite 9497	Henkel	1.4		
QMI505MT™	Henkel: Ablestik	2.4		Au.
QMI519™	Henkel: Ablestik	3.8		Ag, Au. High adhesion.
QMI529HT™	Henkel: Ablestik	7		Ag, Au. For component or die attach. Suitable for devices and solder replacement
QMI718™	Henkel: Ablestik	2.7		Cu.
8290™	Henkel: Ablestik	1.6		Ag,Cu,Au. Low stress die attach adhesive suitable for die size <200 mil.
Tra-Con Tra-Bond 2153	Ellsworth Adhesives	1	2.45	
Tra-Con Supertherm 826M01	Ellsworth Adhesives	2.3	2.55	Diamond.
SUPERTHERM 816H01	Ellsworth Adhesives	2	1.3	
Premium Silver Thermal Epoxy	Arctic Silver	7		

Conclusion

In the market survey performed, many varieties of high end structural products were found and compared against each other. Their applications include heat sinks, semiconductor manufacturing equipment, aerospace industry, optical communications equipment and medical diagnostic imaging instruments. The thermal conductivity of these materials exceeds that of gold, copper and silver and they are very light weight compared to these metals. For the purpose of the CMS tracker, low density materials should be used, partly because they need to be "transparent" to radiation. TPG and carbon fiber materials can be made into thin sheets but these don't transfer heat across their thickness very well. Diamond sheets are available but in smaller dimensions. Foams with eventual encapsulation could also be a good option if they can reach the required strength and durability.

High performance adhesives were also found with thermal conductivity ranging from 1 to 9.1 W/mK. The glue used for the detector will most certainly be a crucial factor because it limits the heat transfer considerably. Silver filled glues exhibit the best performance but could cause problems because of their radiation length. Diamond filled glues are probably a good solution.

The materials considered in the market survey all present promising properties, but they will have to be tested experimentally under the appropriate conditions to draw any conclusions on their usability in the CMS Tracker.

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