TIM deposition and characterization*

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Usage: Application of the TIM on the modules of the Dee. After the application, assembly the Dee. The Dee is going to be implemented on the TFPX of CMS, Cern.

I. INTRODUCTION

The Thermal Interface Material (TIM) is a material, mostly composed of a conductive material that is inserted between two components, it could be between a sensor, CPU or modules and a heat sink enhancing the thermal coupling between them. Mostly the TIM is implemented in systems like computers and sensors to avoid thermal runaway and damaging the components. To explain what is thermal runaway in this system we have to define dark currents. Dark currents is a temperature-dependant current flows into photosensitive devices when not actively being irradiated, in this case the sensors that are in the Dee's. This is due to the random generation of electron and holes within the depletion region of the device, in this case the region that the sensors are in the Dee. It consists of the charges generated in the detector through heat, when no outside radiation is entering the detector. This creates a cycle between the current and dark currents of heat, exponentially escalating temperature creating a thermal runaway and finally damaging all the components.

The TFPX (Tracker Frontal Pixel) it is part of the Inner Tracker of CMS. The TFPX has 8 planar disks that are divided by half, these halves are the Dees.

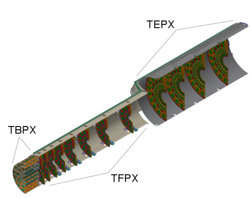

FIG. 1. TFPX

The Dees 2 are currently made of carbon fiber and are the ones holding the thermal system and the modules on the CMS TFPX.

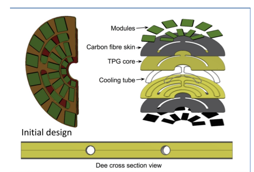

FIG. 2. Dee

The modules are located in the surface of the Dee glued with epoxy.

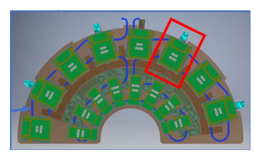

FIG. 3. Location of the modules

The TIM that is used for the modules on the Dee is Moresco + 20μm diamond at 70%.

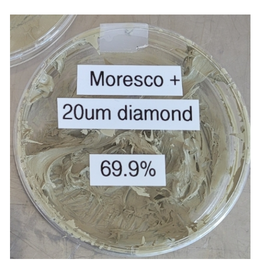

FIG. 4. Moresco + diamond at 70%

This is because according to thermal measurements, the thermal conductivity of the Moresco improves when its mixed with diamonds without suffering radiation damages. In the next image, you can see the thermal conductivity of different concentrations of diamonds with Moresco.

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Material	k (W/mK)
Pure Moresco PPE	0.20 ± 0.02
PPE + 33% diamond (20 um)	0.33 ± 0.03
PPE + 70% diamond (20 um)	1.17 ± 0.11
PPE + Mixed-diameter diamond	0.78 ± 0.08

FIG. 5. Thermal Conductivity of Moresco

According to Souvik's measurements the best thickness of the Moresco + diamonds is at 100μm.

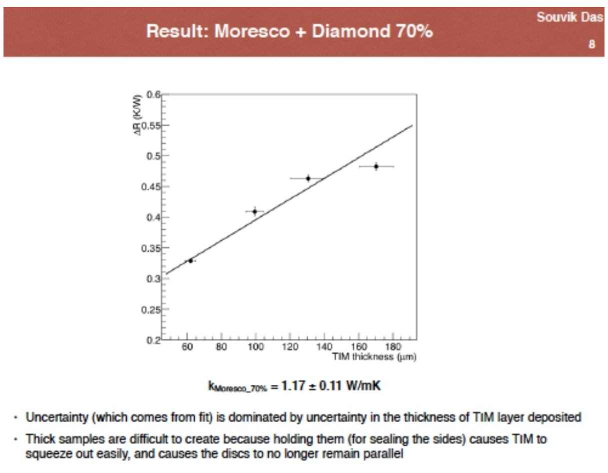

FIG. 6. Best thickness of Moresco

To be able to apply the Moresco on the modules, a double-Y pattern was suggested.

II. DOUBLE-Y PATTERN

The double-Y pattern consists in two parallel lines on the sides and a overlapping line on the center as seen on the figure 7.

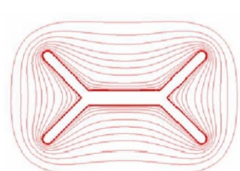

FIG. 7. Double-Y pattern

The double-Y pattern was suggested by Jose Monroy to be able to disperse the TIM across the length and width of the module due to the rectangular shape of the modules. The technique of doing complex shapes of TIM is wildly used to dispense TIM in electronics such as CPU's, GPU's, and other components that requires a material to disperse heat. Usually these components are square shaped surfaces, that makes easy the task of dispersing the TIM equally to each corner applying a moderate force in top of them. In the figure 8 is shown how the scattering of TIM on square surfaces.

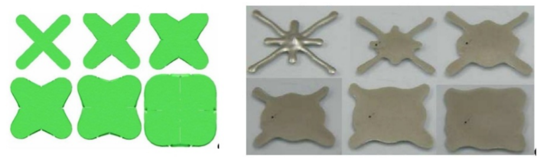

FIG. 8. Scattering of TIM in a CPU

III. TIM DEPOSITION

The TIM deposition was mainly done using a gantry programmed with LabVIEW. The gantry itself can be managed by a proprietary program named Motion Composer, which can move the gantry to the desired velocity and distance; but to be able to run routines, include more components such as cameras, microscopes, etc., and tasks at a desired time and automatically, its easier to program it with LabVIEW. The model of the gantry is the Aerotech A3200.

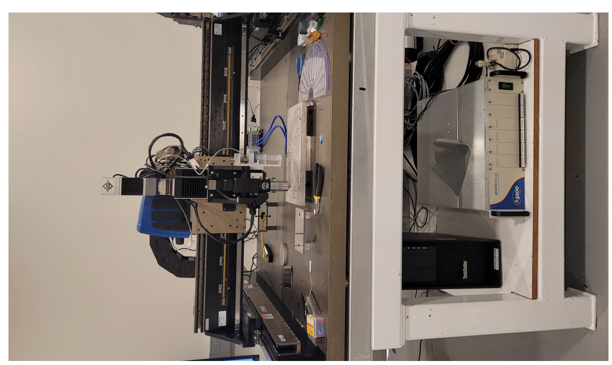

FIG. 9. Aerotech Gantry

To be able to dispense the Moresco + 20μ diamond at 70% we used a dispenser from the company Nordson. This particular dispenser can push up to 100psi.

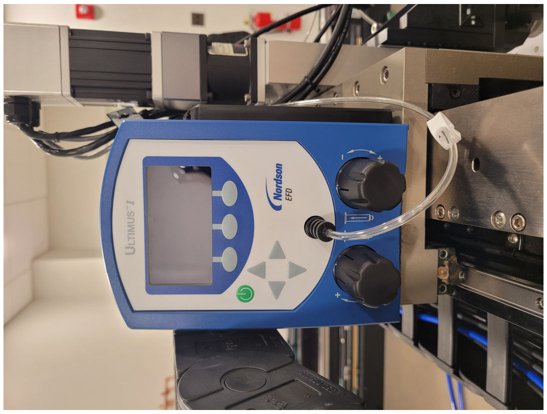

FIG. 10. Dispenser

The gantry has an machined attachment made by Jose Monroy that holds the syringe on the gantry and makes it easier to connect the syringe to the dispenser.

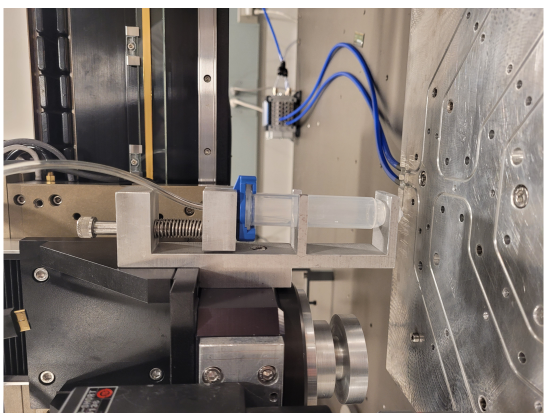

FIG. 11. Syringe attached to the gantry

IV. DISPENSING A DOUBLE-Y PATTERN

The TIM should spread across the length of the ceramic heater that is 35mm x 20mm. This component is part of the set up for the simulation of a thermal runaway. Using the gantry I was able to map out the key points of the desired length. Doing an approximation of after scattering of 1.5mm, the diagonal lines, named l_1 measures 6.5mm and the straight line in the middle of the double Y, named l_2 measures 18.14mm. Finally the angle of the opening between the straight line and diagonal line measures 133.1 degrees, the final diagram can be seen on figure 12. Since LabVIEW can move the gantry using distances, I made the LabVIEW program to ask for the initial point for the double-Y and after that adding the MathScript function on LabVIEW I was able to calculate the remaining points with the distances.

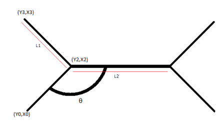

FIG. 12. Points of the double-Y pattern

A very interesting detail to know is that it can be observed that the axis on the figure 12 are backwards. This is because the gantry moves forward in X and to the sides in Y. Taking that perspective of viewer (seen in front of the gantry) the double-Y pattern will be seen as it. The way that it was made, was calculating the next point in reference of the initial point:

$$Y_1 = Y_0 \tag{1}$$

$$X_1 = X_0 - 2l_1 \sin\theta \tag{2}$$

$$Y_2 = Y_0 - l_1 \cos\theta \tag{3}$$

$$X_3 = x_0 - l_1 \sin\theta \tag{4}$$

The routine for the gantry to move was:

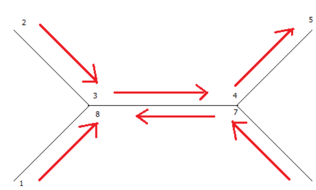

FIG. 13. Movement gantry 1

To dispense the Moresco an olive needle tip was used. This needle tip has an internal circumference of 1.54mm. This needle tip was used because the opening was big enough to pass the Moresco mix and maintaining the precision of the dispensing. When this routine was tested, we saw that the Moresco stretched on the empty spaces of the double-Y pattern. For example on step 4 to 5 was a huge problem. To fix this issue after finishing each line, the Z-axis was lowered to stick the remaining Moresco off the tip of the needle and continue on the routine. After multiple tests, a new routine was thought to decrease the timing that took the gantry to move and avoid the Moresco to stretch (see figure 14).

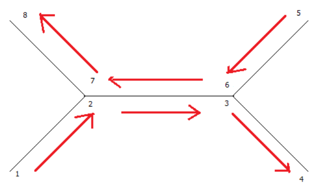

FIG. 14. Movement gantry 2

To code this new routine on LabVIEW some few fixes were done with the equations.

$$X_1 = -l_1 \sin\theta \tag{5}$$
$$Y_1 = l_1 \cos\theta \tag{6}$$
$$X_2 = X_1 \tag{7}$$
$$Y_2 = Y_1 + l_2 \tag{8}$$
$$X_4 = 2l_1 \sin\theta \tag{9}$$
$$Y_4 = 0 \tag{10}$$

A. Double-Y tests

On the first sample, took a load cell to measure how much force required the double-Y to dispense to the sides. To be able to run the load cell used an Arduino and exported the data obtained from it. The numbers are negative because the way the load cell works, it retrieves the data as pushing as a negative and pull as a positive.

Time in seconds	Pressure applied
0.0	-0.099 kg
0.5	-0.196 kg
1.0	-0.265 kg
1.5	-0.321 kg
2.0	-0.407 kg
2.5	-0.407 kg
3.0	-0.527 kg
3.5	-0.591 kg
4.0	-0.644 kg
4.5	-0.679 kg
5.0	-0.716 kg
5.5	-0.729 kg
6.0	-0.769 kg
6.5	-0.838 kg
7.0	-0.929 kg
7.5	-0.960 kg
8.0	0.002 kg
8.5	-0.005 kg

As you can observe it required a lot of force to be able to disperse completely to the sides.

FIG. 15. First double Y

Noticing that the modules are very fragile, it is noticeable that using 1kg of force its too much because on the spreading process it potentially break the module on the dee. Using previous knowledge of Phase 1, the maximum force that the modules could withstand was 200g. Knowing this information, more tests were conducted using the measurements of the plaquette for the thermal runaway tests and the measurements of the mock up module. Having in mind that the maximum force applied was 200g. These measurements are:

Measurements	
Plaquette	Mock up Module
35mm x 20mm	40mm x 25mm

To be able to disperse the double-Y pattern uniformly to the edges, a 5 point tool was built using a glass slide and pieces of metal. Later on, a 3D printer version was made with adjustable positions for the screws to be able to test different pressure points for the double-Y pattern.

B. Results

Next, a list of all the test conducted of the double-Y pattern. Initial measurements for the short double-Y pattern:

Test	Pressure	Length	Width	Width double line	Thickness	Weight
1	30psi	27.25mm	16.35mm	5.53mm	2.03mm	5.30g
2	30psi	27.51mm	15.29mm	5.65mm	2.17mm	5.20g
3	25psi	26.26mm	14.56mm	5.77mm	2.99mm	–
4	20psi	26.47mm	14.45mm	–	3.66mm	–
5	20psi	25.15mm	14.07mm	2.34mm	2.02mm	–
6	18psi	25.52mm	15.24mm	2.38mm	1.69mm	–
7	16psi	25.07mm	15.59mm	1.83mm	1.80mm	–

After applying 200g:

Test	Length	Width	Thickness
1	30.25mm	17.38mm	0.79mm
2	28.25mm	18.38mm	0.77mm
3	30.31mm	19.40mm	0.91mm
4	31.44mm	18.22mm	0.48mm
5	28.73mm	16.42mm	0.43mm
6	27.44mm	16.25mm	0.56mm
7	26.30mm	17.02mm	0.17mm

Initial measurements for the double-Y pattern with the length of the mock up module:

Test	Pressure	Length	Width	Width double line	Thickness
1	25psi	38.19mm	15.27mm	5.51mm	3.05mm
2	20psi	39.50mm	14.03mm	2.80mm	2.88mm
3	25psi	37.80mm	14.50mm	3.13mm	1.72mm
4	20psi	37.92mm	14.86mm	2.23mm	1.08mm
5	18psi	36.70mm	13.72mm	1.68mm	0.78mm

After applying 200g:

Test	Length	Width	Thickness
1	42.06mm	19.28mm	1.61
2	41.94mm	15.30mm	0.47mm
3	39.76mm	16.10mm	0.47mm
4	39.82mm	16.16mm	0.14mm
5	39.19mm	16.73mm	0.10mm

After conducting the tests, you can observe that on the test 5 of the long double-Y pattern the double-Y pattern reached the 0.10mm or 100μ thick but the pattern was severely damaged and it didn't disperse at all to the sides as you can see on the figure 16.

FIG. 16. Non-dispersed double-Y pattern

Additionally, if we compare the data obtained after pressing the Moresco mix with a 200g you can observe that most of them push until 0.40mm thick if its thicker than 1.00mm.

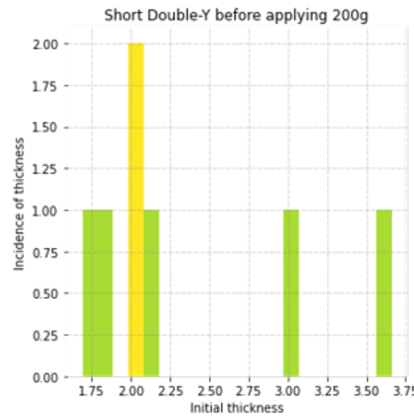

FIG. 17. Short double-Y before applying 200g

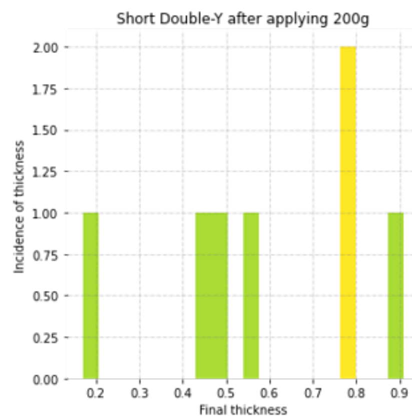

FIG. 18. Short double-Y after applying 200g

You can observe on the figure 18 that the incidence of thickness for the short double-Y pattern are between 0.70mm and 0.80mm. Now for the long double-Y pattern we have:

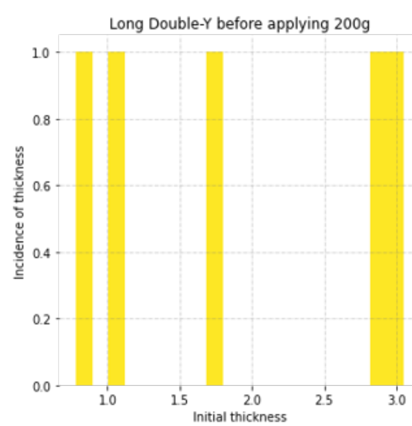

FIG. 19. Long double-Y before applying 200g

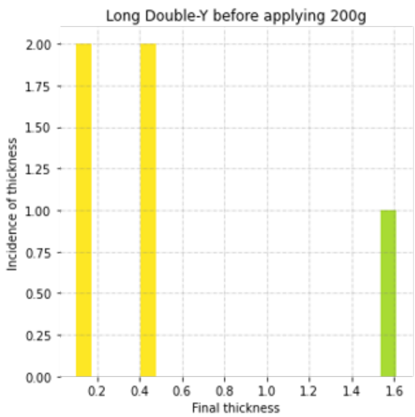

FIG. 20. Long double-Y after applying 200g

In this type of double-Y pattern the greater incidence of thickness was 0.4mm even though on the other type of double-Y didn't was the case, gathering all the info, the media of the thickness is 0.4mm. So that means that the double-Y pattern is not a good shape to disperse in the rectangular space without using a lot of force to disperse it. The best way to apply TIM is by doing a ribbon.

V. RIBBON NEEDLE TIP

After discarding the double-Y pattern, another idea was doing a ribbon. The advantages of the ribbon is that it only needs one routine on the gantry. Since we need several modules on the on the dee having less routines on the gantry will guarantee that it will take less time dispensing. The doctorate student, Xingchen Fan ordered the ribbon needles from China, luckily they arrived at the same week that the idea of the double-Y pattern was discarded. To perform the test, initially we started off with the 5 point spreader to disperse it better to the sides.

One thing that it was noticeable was that for all the test conducted, the Moresco was being recycled. In the recycling process the Moresco got contaminated with some dust from the surfaces, and glass shards.This made the Moresco more viscous and it took more force to push for the tests. New Moresco had to be mixed. Moresco with 20μ, $36\mu - 54\mu$, and $54\mu - 80\mu$ diamond was mixed.

The ribbon needle tips that were used before finding the best design were:

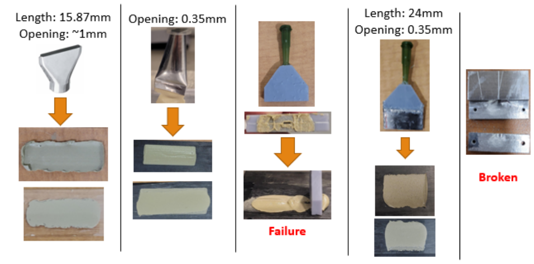

FIG. 21. Ribbon Needles

The majority of the discarded needles were mainly because they were dispensing the ribbon too thick. To be able to achieve a good ribbon with the desired thickness, the ribbon had to have an opening of 100μ, use a very low pressure and lower the needle as close to the surface as possible. The working needle is shown on the figure 22

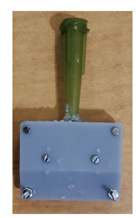

FIG. 22. Working needle tip

One thing that was noticeable was bubbles on the sample, shown on the figure 23.

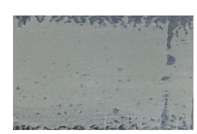

FIG. 23. Bubbles on Moresco sample

Initially, it was thought that the bubbles came up from the syringe and the deposition, but after observing carefully and taking a video these "bubbles" were generated by the stretching of the Moresco on the surface and due to the low pressure it created these holes, not bubbles.

To be able to fix this problem, a scraper was installed on the back of the needle tip to flatten up the surface, achieve the desired thickness and fill these holes. The scraper installed on the needle tip can be seen on the figure 24.

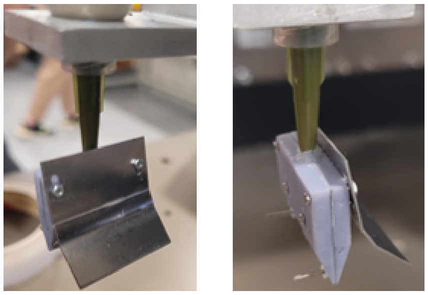

FIG. 24. Scraper installed on the needle tip

To install and make the scraper usable, it had to be calibrated using the surface as a base and using the Z-axis of the gantry, the thickness of the Moresco was about the same as the distance of the surface from the scraper. After using the scraper, a good amount of Moresco was built on the back of it, but thankfully was useful to fill the gaps on the sample.

Since the gantry has to mass produce, another run to do another ribbon was made without cleaning the back of the scraper to see if the ribbon was going to be damaged, and indeed it was. To solve this issue, using a vacuum pump, install on the back of the scraper a small tube with an opening. This tube will be connected to a small box to collect the Moresco and prevent the vacuum pump be damaged by the Moresco.

Another thing noted was that the surface of the sample has to be leveled, otherwise it will have a thick side or the scraper can touch the surface and damage it. This was observed while dispensing in a sample with the tubes attached to the carbon fiber sandwich.

Lastly, after dispensing on the carbon-fiber sandwich with the tubes attached, this sample was taken to the thermal runaway test to seek if the simulations and expectations of the gantry dispensed Moresco reach up to the desired temperature. After this step, next thing is to perfect the needle tip by making the same model in stainless steel and calibrate the scraper with the new needle tip, and build the vacuum pump setup.

VI. REFERENCES

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