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TEST REPORT
T777 Reliability Test Report

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T777 Reliability Test Report

T777 is a high performance Polymer Solder Hybrid (PSH) material and is the latest addition to Chomerics' THERMFLOW® family of Phase Change Materials (PCM). T777 has very low thermal impedance, enhanced thermal stability, and excellent long-term reliability demonstrated by End-Of-Life performance through 5 years at 70°C. T777 was developed for next generation Intel microprocessors for mobile applications. It was optimized for Intel Santa Rosa platform, Intel CPU chips and verified with Intel Yonah test vehicle.

Thermal Stability

T777 PSH material incorporates low-melt alloy fillers as well as polymer systems to maximize both thermal conductivity and thermo-oxidative stability. It showed excellent thermal stability up to 250°C (Figure 1-a) and weight loss less than 0.2% after 48hrs at 125°C (Figure 1-b) based on TGA (thermo gravimetric analysis).

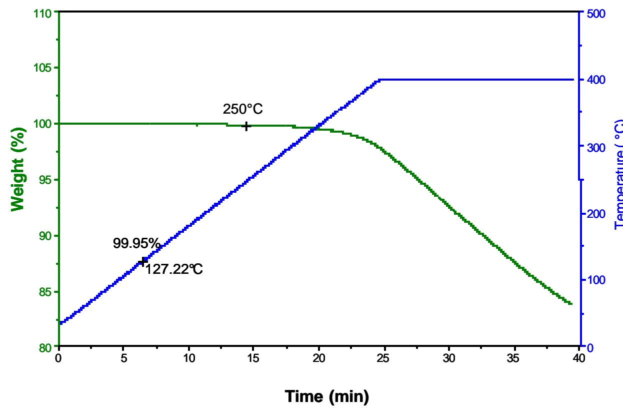
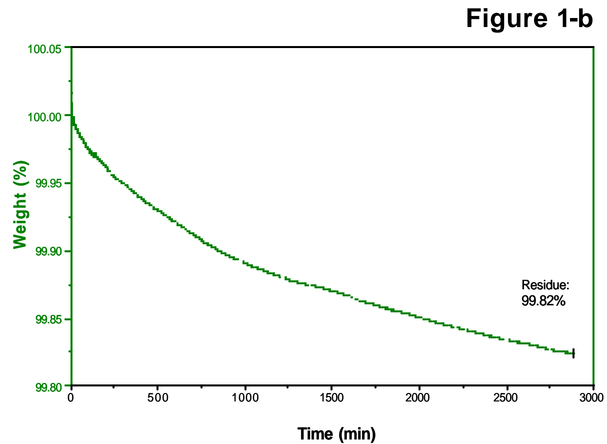


Figure 1-a

Figure 1-b



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Reliability Test Method

The long term reliability of T777 PSH material was evaluated by thermal impedance measurements after accelerated aging at high temperature, humidity, and temperature cycling:

- Thermal aging: baking up to 2000 hours at two different temperatures: 95°C and 120°C
- Thermal - humidity aging: 1000 hours at 85°C/85% relative humidity
- Temperature cycle: 400 cycles of -40°C to +120°C

T777 pads were subjected to high temperature baking conditions and tested for thermal performance using two methods. One method was a traditional ASTM D5470 Guard Heater Method based on steady-state heat flux condition. The ASTM D5470 tester was a convenient standard tool to measure and compare TIM performance but it required highly controlled, flat, co-planar surfaces with uniform temperatures. Furthermore, one could not perform thermal aging, humidity, temperature cycle testing of phase change type of materials under realistic operating conditions using just the ASTM D5470 tester.

The other method utilized was an application oriented mobile TIM test method which simulates actual operating conditions as shown by the simplified diagram of Figure 2. A bare flip-chip silicon die generated controlled power output (P) for two types of heating conditions: uniform heating and core heating (hot-spot). T-type thermocouples were used to measure temperatures of the heat spreader (T_p) and the ambient. The junction temperature (T_j) was measured by electrical method using the temperature dependence of voltage of the diodes in the silicon die. Thermal impedance of the TIM was calculated from the temperature difference across the junction-spreader interface and the power output, $(T_j\text{-}T_p)/P$.

This mobile TIM testing solution was developed not only to capture real use application but also to facilitate reliability testing. The TIM test vehicle fixtures were subjected to accelerated stress conditions and periodically removed for thermal impedance measurements. The data collected was used to develop a degradation model which was then used to predict End-of-Life thermal performance, for example after 5 years operation at 70°C.

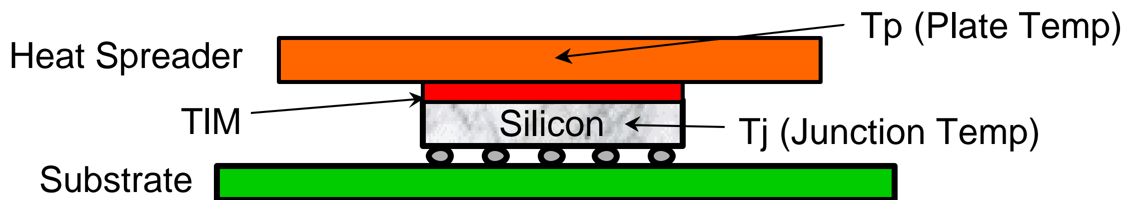

Fig.2

Equipment

A. Mobile TIM Test Vehicles (TTVs) with Silicon die
B. Test board with TTV socket
C. Copper Heat Spreader with two Pin Fin heat sinks attached with screws
D. Agilent E3634A DC power supply for TTVs and HY1803D DC power supply for fans
E. Fluke NetDAQ Data logger

Fixture Assembly: (see Figure 3)

1. Mobile TIM test vehicle was inserted into the socket on the test board. A pin connecter was attached to the edge connector on the board and the data logger and power supply.
2. 15x15mm T777 pad was applied to the copper heat spreader by removing the T777 pad from the white liner and applying the pad to the heat spreader at room temperature with finger pressure. The clear release liner was removed before assembly.
3. The copper heat spreader was rested evenly on the top of the die and the screws tightened in sequence. The spring screws were designed to apply 90psi pressure.
4. Three holes had been machined on the heat spreader for three T-type thermocouples: left and right sides of the plate under the heat sinks, and the third one on top of the plate.
5. After the fixture assembly was completed, fans were placed on top of the heat sinks and powered up to an initial 3W.

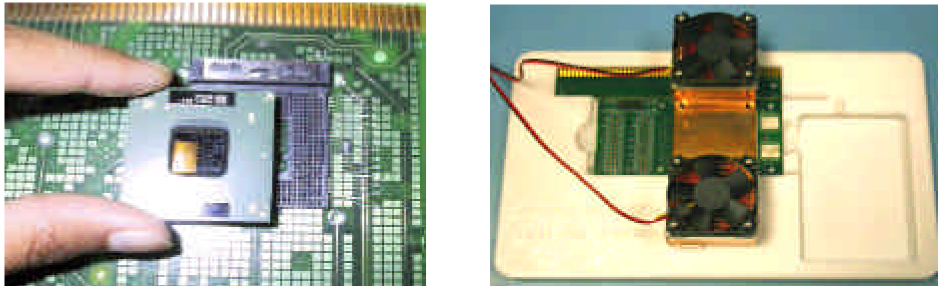

Fig. 3

Reliability Testing:

The TTV was powered up to 35W or 50W depending on the test conditions. Both uniform heating and core heating conditions were tested. For uniform heating, the entire silicon die was heated uniformly and the junction temperature was measured in the center of the die. For core heating, only the top right quadrant was heated and its junction temperature was measured in the center of that quadrant. Core heating resulted in higher heat flux simulating a hot-spot and represented a more realistic (and thermally challenging) test condition. Each test lasted about 20 minutes for steady state measurements. Five separate test vehicles were used for each test condition.

1. High temperature aging at 95°C and 120°C for 2000 hours

   Apparatus: Forced convection Blue M ovens were set at 95°C and 120°C. Temperature uniformity was +/- 5°C within the ovens.
   Procedure: Five test vehicle fixtures were placed in the forced convection oven maintained at the bake temperature. At specific time intervals, the fixtures were removed from the oven, allowed to cool to room temperature for two hours minimum, powered up and tested. The test time intervals were shorter earlier in the testing (e.g. 100, 200,… hours) and longer later in the testing (e.g. 1200, 1600,…hours). The thermal impedance (°C/W) between die and plate was calculated by measuring die junction temperature (either die center or core center), plate temperature and power.

2. High temperature and humidity exposure 85°C, 85%RH for 1000 hours

   Apparatus: A Cincinnati sub-zero humidity cabinet chamber maintained at 85°C (+/-2°C) at a relative humidity of 85% (+/- 5%)
   Procedure: Five test vehicle fixtures were placed in the humidity chamber and fully exposed without any protection for the surfaces. At specific time intervals, the fixtures were removed from the oven, allowed to acclimate to room temperature for two hours minimum, powered up and tested. As before, the thermal impedance (°C/W) between die and plate was calculated by measuring die junction temperature, plate temperature and power.

3. Temperature cycling between -40°C and +120°C for 400 cycles

   Apparatus: A thermal cycling chamber from Sun Electronic System was used for thermal cycling between -40°C and +120°C.
   Procedure: Five test vehicle fixtures were placed in the thermal cycling chamber and fully exposed without any protection for the surfaces. The dwell time at lower and upper temperature set points (-40°C and +120°C respectively) was 10minutes each with a ramp rate of 10°C/minute. At specific cycle intervals (every 100 cycles), the fixtures were removed from thoven, allowed to acclimate to room temperature for two hours minimum, powered up and tested. As before, the thermal impedance (°C/W) between die and plate was calculated by measuring die junction temperature, plate temperature and power.

Results

1. High temperature aging at 95°C and 120°C for 2000 hours

Figure 4 shows the junction-to-plate resistance values (°C/W) for T777 TTV samples baked at 95 and 120°C. Each TTV was measured with uniform heating conditions at 50W power and core heating conditions at 35W power. Since core heating method supplies power to only one-fourth the area of the silicon die resulting in higher heat flux, the typical thermal resistance values are higher than for the uniform heating method.

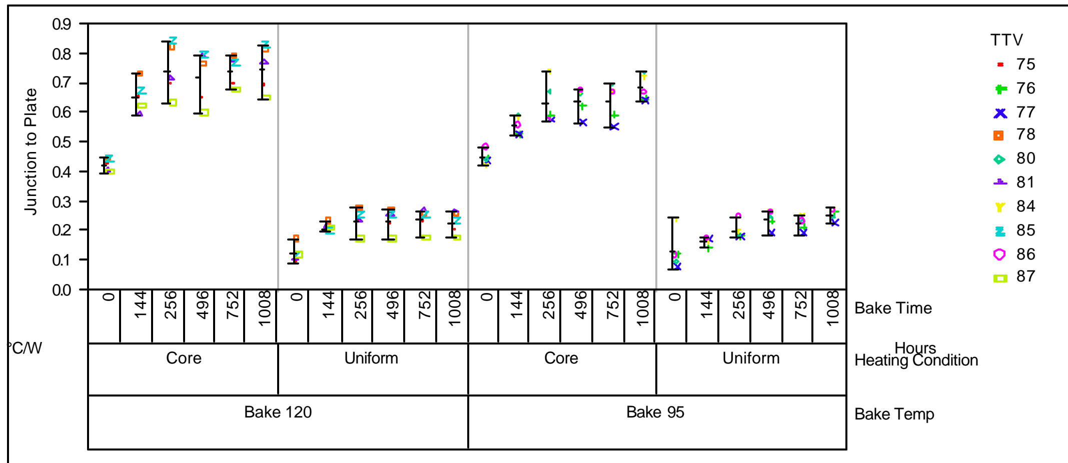

Fig.4

The junction-to-plate resistance values can be converted to TIM impedance (°C-cm²/W) by using test vehicle correlation equations. The correlation varies based on location of the sensor on the test vehicle and the test vehicle itself. Figures 5-a and 5-b are the plots for T777 thermal impedance versus aging time for core heating conditions at 35W power and accelerated aging temperatures of 95 and 120°C. The initial (t = 0) thermal impedance was about 0.036 °C-cm²/W. The thermal impedance increased over the first 500 hours and then did not change much through the end of the test at 2000 hours which demonstrates the reliable thermal performance of T777. The thermal impedance values at saturation were 0.08°C-cm²/W for 95°C aging and 0.11°C-cm²/W for 120°C aging.

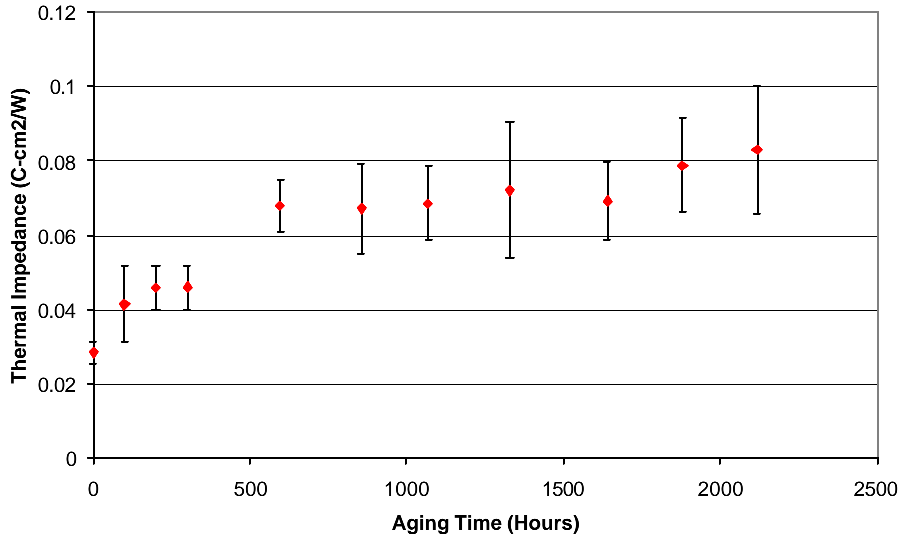

Fig.5-a: 95°C aging with core heating

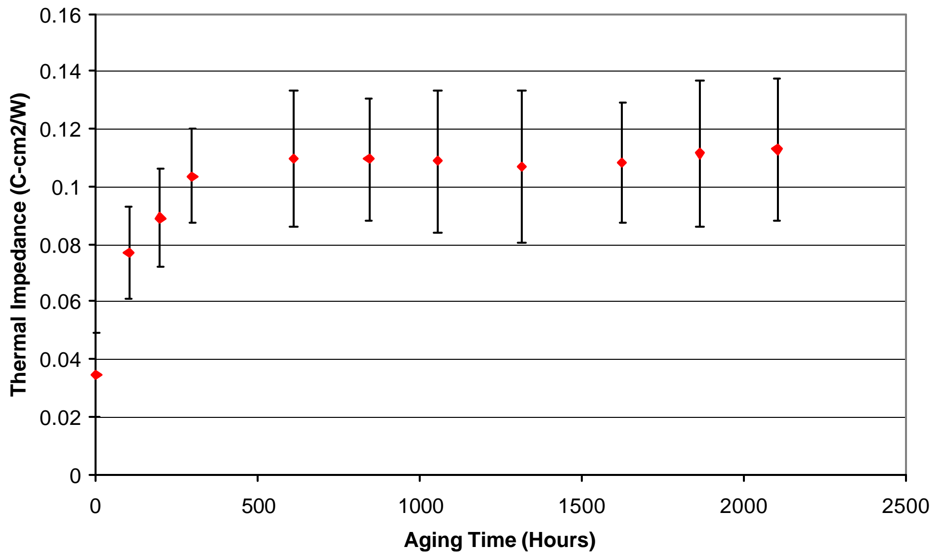

Fig.5-b: 120°C aging with core heating

2. High temperature and humidity exposure 85°C, 85%RH for 1000 hours

Figure 6 shows the thermal impedance of T777 at 35W power for core heating conditions. The initial (t = 0) thermal impedance was about 0.036 °C-cm²/W. The thermal impedance increased over the first 300 hours and reached a saturated value of about 0.14°C-cm²/W and then did not change much through the end of the test at 1000 hours which demonstrates the reliable temperature-humidity performance of T777.

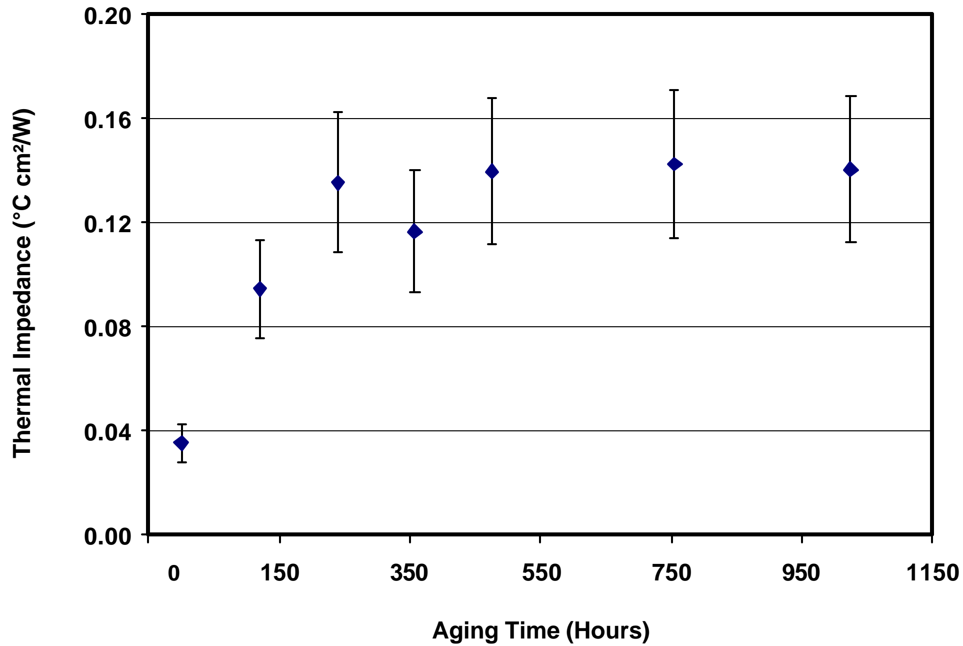

Fig. 6

3. Temperature cycling between -40°C and +120°C for 400 cycles

Figure 7 shows the thermal impedance of T777 at 35W power for core heating conditions. The initial (t = 0) thermal impedance was about 0.046 °C-cm²/W. The thermal impedance increased over the first 300 cycles and reached a saturated value of about 0.09°C-cm²/W and then did not change much through the end of the test at 400 cycles which demonstrates the reliable temperature cycling performance of T777.

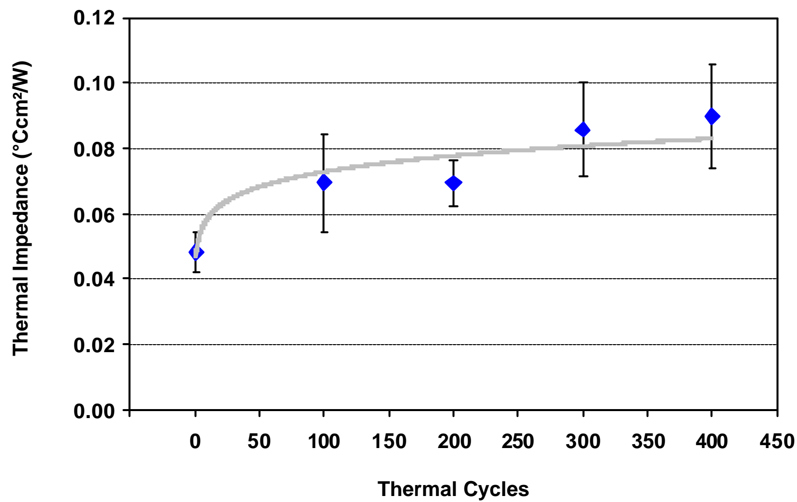

Fig. 7

Reliability Comparison of T777 versus Grease

Figure 8 shows the reliability performance of T777 compared to a commonly used thermal grease material. The test set-up and method were identical for both materials, as were the test conditions: 50W, uniform heating, 120°C aging. The initial (t=0) thermal impedance of the grease measured 0.07°C-cm²/W which was much higher than 0.01°C-cm²/W for T777. As shown in Figure 7, the thermal impedance of the grease increased rapidly through 1000 hours and reached about 0.28 °C-cm²/W. On the other hand, the thermal impedance of T777 increased only over the first 200 hours and then saturated at a relatively low value of 0.05 °C-cm²/W and showed no further change up to 2000 hours.

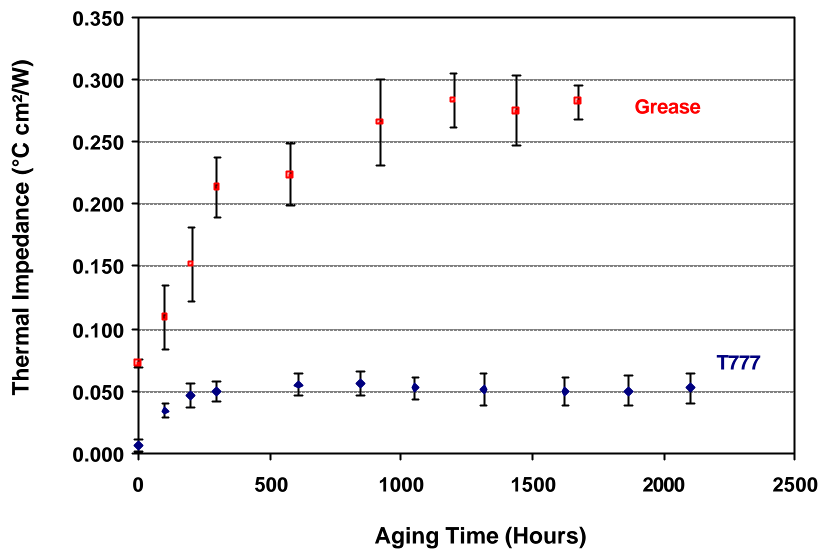

Fig. 8

End of Life (EOL) Performance

For good initial (t =0) performance, the TIM should have filler and resin system optimized for high thermal conductivity, thin bond line, and good wetting at the interfaces. For good End-Of-Life performance, the TIM should be low in volatiles (minimum dry-out), resistant to oxidation, and have minimum de-lamination. The data in Figures 5-a, 5-b measured TIM degradation (increase in thermal impedance) under accelerated stress conditions (high temperatures). The data was fitted to a non-linear Arrhenius-type of degradation model which can then be used to predict thermal impedance at different operating temperatures after different number of years in use.

Figure 9 shows results of the degradation model of the estimated thermal impedance of T777 after it has been in use at 70°C for 5 years. The End-Of-Life thermal impedance is estimated to be less than 0.07 °C-cm²/W from the initial value of 0.036 °C-cm²/W. This reflects T777's high performance and high reliability and meets the requirement for next generation microprocessors.

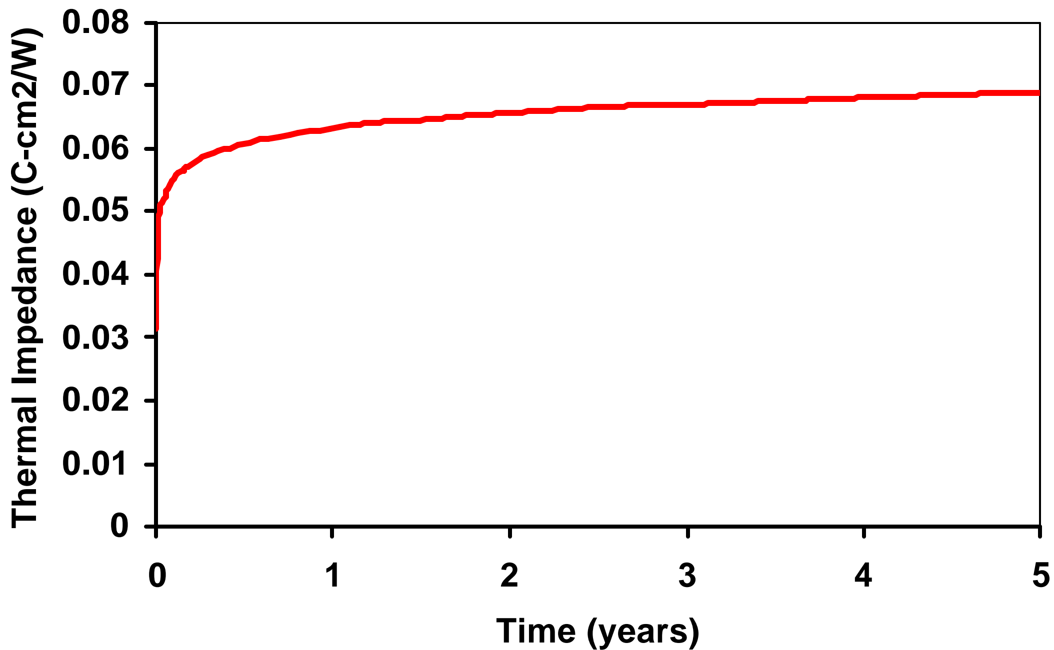

Fig.9