# ALIGNED CARBON NANOTUBES TO REDUCE CONTACT THERMAL IMPEDANCE

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**Introduction**

Heat dissipation is the most critical problem that limits the performance, power, reliability and further miniaturization of microelectronics. The thermal performance of these devices is greatly affected by the thermal resistance associated with interface between the heat sink and heat source. The improvement of a thermal contact is associated with a decrease of the thermal resistance imposed by this interface as the heat flows across it [1-5]. As surfaces are never perfectly flat, the interface comprises point contacts at asperities and air pockets. Some heat is conducted through the physical contact points, but much more is transmitted through the air gaps. Since air is a poor conductor of heat, it should be replaced by a more conductive material to increase the joint conductivity and thus improve heat flow across the thermal interface. Use of suitable interface materials can thus have a significant role in lowering thermal contact resistance.

Carbon nanotubes (CNT) with their light weight and high thermal conductivity value have the potential to be used as thermal interface material. The high intrinsic thermal conductivity of CNT [5-6] suggests many heat transfer enhancement applications. They also have shown that CNT arrays with different properties produce measurable variations in thermal enhancement. Thus the CNT can play a significant role in reducing the thermal resistance by lowering or eliminating the micro-gaps at the same time providing a high thermal conductivity path through them. The focus of this study is first, to study the effect of thermal contact resistance on heat transfer capability of high thermal conductivity materials and second is to demonstrate the effectiveness of CNT as thermal interface materials.

**Material Preparation**

The Carbon Chemical vapor deposition (CVD) method was used to grow CNT on the quartz piece because of its potential to produce well aligned CNT with a positional control at nanoscale. The CVD method synthesis is essentially a two-step process consisting of a catalyst preparation step followed by the actual synthesis of the CNT. We managed to grow aligned CNTs with thickness ranging from several micrometers to about 200 um with a narrow diameter distribution around 10 nm (Fig. 1a and 1b). The thickness was monitored precisely by the growth time. However use of Raman spectroscopy shows that Aligned CNT film is made of mixture of single and multiwalled carbon nanotubes. Even though our process is focused on making 100% multi-walled carbon nanotubes (MWNTs), it produced a mixture of single-walled carbon nanotubes (SWNTs) as well.

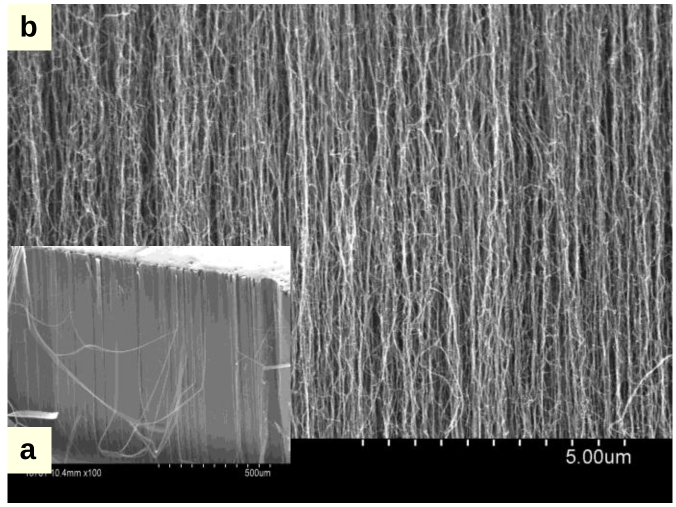


**Fig. 1** (a) SEM image of Aligned Carbon Nanotubes. (b) Higher magnification image showing the size and the orientation of carbon nanotubes.

**Fig. 2** ASTM D5470 Thermal Impedance Test.

**Experimental setup**

A variety of thermal interface materials was tested to establish a baseline of current technology. The testing was done on an ASTM D5470 compliant test. The device consists of a DC power supply driving a heat source, a constant temperature bath to maintain the temperature at the cold plate, pair of flat polished aluminum blocks with temperature probe wells drilled into the center of the blocks at precise axial locations, a pneumatic ram to apply a constant pressure to the system with a load cell to read that pressure and a thermometer with four calibrated RTD probes. A simple computer data acquisition program reads the temperatures from the probes and when thermal equilibrium is established, the data is transferred to an Excel spread sheet with formulas installed to perform the calculation of the Thermal Interface Impedance. A photograph of the system is shown in Figure 2.

## Results and Discussion

The materials tested are listed in Table 1. They were tested at three power levels (19, 38 and 57 W/in2) and five loadings (75, 150, 225, 300 and 375psi) in random sequence. Two repetitions of the test matrix were performed for all the materials using the one inch square test blocks, and then tests were performed using the two inch square test blocks at a single power and the two highest loadings. Two of the materials, Arctic Silver and Aremco 640, were tested over the full matrix with the two inch blocks.

**Table 1. List of TIMs Tested As a Baseline**

| Manufacturer | Product |
|---|---|
| Arctic Silver, Inc. | Arctic Silver 5 |
| Aremco Products, Inc. | 639 Heat-Away Grease (Aluminum) |
| Aremco Products, Inc. | 640 Heat-Away Grease (Copper) |
| Aremco Products, Inc. | 641 Heat-Away Grease (Silver) |
| Parker Chomerics | Cho-Seal S6305 |
| Chemtronics Circuit Works | Boron Nitride Heat Sink Grease |
| Laird Technologies | T-gon 805 |
| Loctite Power Devices | Powerfilm 51 |
| Loctite Power Devices | Powerstrate 51 |
| Loctite Power Devices | Powerstrate Extreme |
| Omega Engineering, Inc. | Omegatherm 201 |

The thermal impedance values obtained were analyzed with 2-way ANOVA and found to be independent of the power input and dependent on the loading. A typical plot of the data as a function of loading is shown in Figure 3.

The TIMs tested all had the expected improvement in effectiveness as the loading increased. The thermal impedance values obtained in the testing are shown in Table 2 for all the materials tested. The lowest thermal impedance measured with the 1" blocks was for the Arctic Silver at loadings of 300 and 375psi GHz in 500 MHz steps.

For all processed materials based nanotube, nanofibers and exfoliated graphite, the test measurement was set using optimized conditions with a pressure of 300lb/inch and input current of 1 Amp. We used different concentrations of nano-additives (low, medium and high). The results show that as concentration of nano-additives increases the thermal impedance decreases (Table 2). Significant improvement was observed in the case of aligned carbon nanotubes with denser nanotube growth (Table 2).

## Conclusions

The arrangement of CNTs in an aligned manner and the quality of the CNT array produced using the CVD method could be the key factors responsible for lowering the thermal impedance value. The above study will be extended for increased volume fraction of CNTs in the TIM film and also for the case CNT film TIM used with other materials like aluminum and graphite with different values of surface roughness.

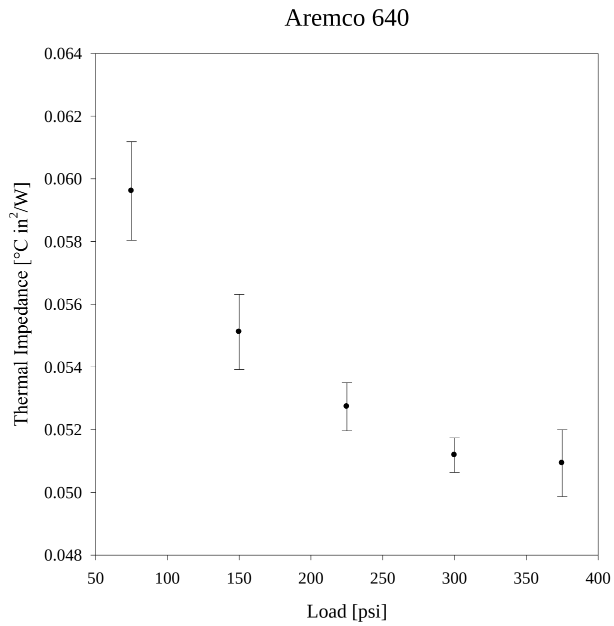


**Fig. 3** 1" block Thermal Impedance versus Aremco 640 copper loaded heat sink compound

**Table 2. Results of TIMs tested Materials**

| Product | Thermal Impedance [°C in²/W] |
|---|---|
| Dry Test | 0.160 |
| Arctic Silver | 0.013 |
| Aremco 640 | 0.060 |
| Circuit Works Grease | 0.018 |
| Omegatherm 201 | 0.054 |
| PowerFilm 51 | 0.474 |
| Aligned CNT (11%) | 0.0092 |
| Aligned CNT (36%) | 0.0054 |

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**References**

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