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Application of multiwall carbon nanotubes for thermal dissipation in a micro-processor

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Abstract. One of the most valuable properties of the carbon nanotubes materials is its high thermal conductivity with 2000 W/m.K (compared to thermal conductivity of Ag 419 W/m.K). It suggested an approach in applying the CNTs in thermal dissipation media to improve the performance of computer processors and other high power electronic devices. In this research, the multiwall carbon nanotubes (MWCNTs) made by thermal chemical vapour deposition (CVD) at our laboratory was employed as the heat dissipation media in a microprocessor a Personal Computer with configuration: Intel Pentium IV 3.066 GHz, 512Mb of RAM and Windows XP Service Pack 2 Operating System. We directly measured the temperature of the microprocessor during the operation of the computer in two modes: 100% usage CPU mode and over-clocking mode. The measured results showed that when using our thermal dissipation media (a mixture of the mentioned commercial thermal compound and 2 wt.%. MWCNTs), the temperature of the microprocessor decreased 5°C, and the time for increasing the temperature of the microprocessor was three times longer than that when using commercial thermal compound. In over-clocking mode, the processor speed reached 3.8 GHz with 165 MHz of system bus clock speed; it was 1.24 times higher than that in non over-clocking mode. The results confirmed a promising way of using MWCNTs as the thermal dissipation media for microprocessor and high power electronic devices.

Keywords: MWCNTs, thermal compound, microprocessor, thermal dispersion, thermal dissipation.

1. Introduction
Currently the density and the speed of electronic and optoelectronic devices are increasing very quickly. For long-term operation, such devices consume power and liberate thermal energy that seriously decline the performance of the devices or even destroy them. Finding an effective way for thermal dissipation therefore becomes a very important issue. The future of high density, high power electronic and optoelectronic devices strongly rely on the thermal dissipation management.

Carbon nanotubes (CNTs) was known as the highest thermal conductivity materials compare to diamond or other metallic materials (\(K_{\text{CNTs}} = 3000\ \text{W/m.K}\) compared to \(K_{\text{Ag}} = 419\ \text{W/m.K}\) [1]. This valuable property of the CNTs opened up an obvious way to utilize the CNTs as an ideal thermal dissipation media in high power, high-density electronic devices. In this paper, we present the initial results on thermal dissipation efficiency in a microprocessor of personal computer (P.C.) using multiwall CNTs as thermal matching media. A simple and effective model was developed for
evaluation of the thermal dissipation efficiency by directly measuring the temperature of the microprocessor.

2. Experimental
A commercial silver base thermal grease for PC (named commercial thermal compound) and its mixture with MWCNTs (named CNTs-thermal compound) were utilized as the thermal matching media on the PC (Intel Pentium IV, 3.066 GHz, 512Mb RAM, Windows XP Service Pack 2 Operating System). The thermal dispersive efficiency is evaluated by directly measuring the temperature and temperature response of the CPU using a dedicate software and a temperature sensor built-in inside the microprocessor. Since the surface of the CPU and the heat-sink is not entirely flat, there are many tiny gaps between the two components that make a negative effect on the heat transfer. Material with high thermal conductivity is needed to fill these gaps and improve heat transfer between the CPU and the heat-sink. The testing thermal dissipation compound is located between the surface of the CPU and the CPU fan (heat-sink) as shown in figure 1.

Multiwall carbon nanotubes (MWCNTs) were produced by thermal CVD technique on iron mesh catalyst in a gas mixture of acetylene, hydrogen and nitrogen [2]. The diameter and length of the grown MWCNTs used in this experiment was 20-80 nm, several µm, respectively. Typical Scanning Electron Microscopy (SEM) image of the grown MWCNTs is shown in figure 2. Such MWCNTs have been successfully applied for field emission and advanced plating applications [3-5]. This paper is our first report on utilizing the grown MWCNTs for thermal dissipation application. Functionalized MWCNTs was mixed with the commercial thermal compound mentioned above at different concentrations by mechanical method. The thermal matching media in a volume of 0.12 ml was carefully applied on an area of 3x3 cm² of the microprocessor. The thickness of the thermal matching media was approximately 130 µm. Figure 3 shows a SEM image of the 2 wt.%. CNTs thermal compound. It showed that the CNTs were well dispersed in the compound. The testing computer is kept in an environment of 26°C for all measurements. Figure 4 shows the experiment configuration on the actual microprocessor of the PC.

Figure 1. Schematics of the thermal dispersive system of the CPU [2].
3. Results and discussion

We measured directly the temperature of the microprocessor during the operation of the computer in 100% usage CPU mode. Figure 5 is the measured temperature of the microprocessor as a function of
working time in three cases: (i) no thermal matching media, (ii) utilizing commercial thermal compound and (iii) CNT-thermal compound. It is clearly seen from figure 5 that without thermal matching media, the temperature of the microprocessor reached 85°C within 20 seconds and the computer was automatically shutdown. This obviously confirmed the essential of the thermal matching media for the device. By using 2 wt.% CNTs thermal compound, the temperature increasing time and the maximum temperature of the microprocessor were 200 seconds and 65°C, respectively. Whereas these values are 75 seconds and 70°C for the commercial thermal compound, respectively. The measurement was repeated many times and remained stable for long periods of operation. The improvement of the thermal dissipation is absolutely attributed by the added MWCNTs component. Noted that 2 wt.% CNTs was optimized for keeping the adhesive and sticking property of the media.

![Figure 5. The temperature of the microprocessor as a function of working time.](image)

The temperature increase of the microprocessor can be expressed by differential equation

\[
\frac{dT}{dt} = \frac{(P - J)}{C}, \tag{1}
\]

where \(T\) is temperature of the microprocessor, \(P\) is the radiate thermal power of the microprocessor, \(J\) is the rate of radiate heat flow and \(C\) is heat capacity of the system

\[
J = \frac{(T - T_0)}{R}, \tag{2}
\]

where \(R\) is heat resistance of thermal dispersive system, and \(T_0\) is environmental temperature (\(T = 26\)°C). From equations (1) and (2), we have:

\[
\frac{dT}{dt} = \frac{(P - T - T_0)}{R} \cdot \frac{1}{C}, \tag{3}
\]

\[
\frac{dT}{dt} = \frac{PR + T_0 - T}{RC}, \tag{4}
\]

\[
\frac{dT}{PR + T_0 - T} = \frac{dt}{RC}. \tag{5}
\]
Since the temperature of the microprocessor at the time $t = 0$ is slightly different from $T_0$ due to the running of the computer before starting to count the time so from equation (5) we have:

$$\int_{T_0}^{T} \frac{dT}{PR + T_0 - T} = \int_{0}^{t} \frac{dt}{RC} ,$$  \hspace{1cm} (6)

$$- \int_{T_0}^{T} \frac{d(PR + T_0 - T)}{PR + T_0 - T} = \frac{1}{RC} \int_{0}^{t} dt ,$$  \hspace{1cm} (7)

$$- \ln(PR + T_0 - T)|_{T_0}^{T} = \frac{t}{RC} ,$$  \hspace{1cm} (8)

$$\ln \left( \frac{PR + T_0 - T}{PR + T_0 - T} \right) = - \frac{t}{RC} ,$$  \hspace{1cm} (9)

$$PR + T_0 - T = e^{- \frac{t}{RC}} ,$$  \hspace{1cm} (10)

$$PR + T_0 - T = (PR + T_0 - T_0)e^{- \frac{t}{RC}} ,$$  \hspace{1cm} (11)

$$T = (PR + T_0) - (PR + T_0 - T_0)e^{- \frac{t}{RC}} .$$  \hspace{1cm} (12)
Thus, temperature $T$ of the microprocessor increases as an exponential function of working time $t$:

$$T = a - be^{-\frac{t}{c}}, \quad (13)$$

where:

$$a = PR + T_0; \quad b = PR + T_0 - T_1; \quad c = RC. \quad (14)$$

Figures 6 and 7 showed the measured and fitting results according to equation 13 of the microprocessor’s temperature as a function of working time for the commercial and CNTs-thermal compounds, respectively. The fitting results showed a function $T = 68.3 - 37.1e^{-\frac{t}{12.6}} \ (°C)$ for commercial compound and $T = 64.6 - 37.8e^{-\frac{t}{37.7}} \ (°C)$ for CNTs-thermal compound. The fitting curves excellently matched with the measured values. Noted that the values of $P$ (radiate thermal power of the microprocessor) and $T_0$ do not depend on the nature of thermal dissipation media. The value of $T_1$, $R$ and $C$ depend on the type of thermal matching media. For the case of using commercial thermal compound matching media, we have:

$$PR_1 + T_0 = 68.3, \quad (15)$$
$$PR_1 + T_0 - T_1 = 37.1, \quad (16)$$
$$R_1C_1 = 12.6. \quad (17)$$

For the case of using CNT thermal compound matching media, we have:

$$PR_2 + T_0 = 64.4, \quad (18)$$
$$PR_2 + T_0 - T_2 = 37.8, \quad (19)$$
$$R_2C_2 = 37.7. \quad (20)$$

From equations (15)-(20) and $T_0 = 26°C$, we received: $T_1 = 31.2°C; \quad T_2 = 26.8°C; \quad PR_1 = 42.3; \quad R_1C_1 = 12.6; \quad PR_2 = 38.6; \quad R_2C_2 = 37.7; \quad R_1/R_2 = 42.3/38/6 = 1.0958$ and $C_1/C_2 = (R_1/R_2)\times(12.6/37.7 = 0.305 \text{ or } C_2 = 3.279C_1$. These values confirmed that the heat capacity of the system with CNTs thermal compound ($C_2$) was more than three times larger than that with the commercial thermal compound ($C_1$).

4. Conclusion

The results confirmed the advantage of the MWCNTs for the thermal dissipation media for microprocessor of the PC or high power electronic devices in general. The measured and calculated results showed that temperature of CPU increases as an exponential function of working time. When using CNTs thermal compound, the temperature of the microprocessor decreased 5°C, and the heat capacity and the time for increasing the temperature of the microprocessor was more than three times larger than that when using commercial thermal compound.

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