# CARBON NANOTUBE COATINGS FOR HEAT EXCHANGE ENHANCEMENT OF MICROELECTRONIC DEVICES

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**Abstract**

High performance cooling technique is required now for advanced microelectronic devices. Carbon nanotubes (CNT) with extremely high thermal conductivity (1800–3000 W/(m·K) at room temperature) and chemical stability can be useful for design of a new type thermal interface coating for silicon and metal surfaces with low thermal resistance. By using of chemical vapor deposition (CVD) and plasma enhanced (PECVD) methods aligned and nonaligned CNT of different forms can be fabricated and tested as effective heat exchange coating for micro and macro scale units such as microchannel cooler, microscale heat pipes and coolers with static discharge. Typical heat flux can reach 0.8–1.2 MW/m$^2$ for boiling in distilled water. Preliminary tests based on study of heat exchange of hot wire covered with CNT (nonalignment 0.9–1.2 nm diameter with length 0.8–2.2 mkm) in liquid environment have showed the increasing of heat exchange rate more than five times, and this rate can increase up to 18000 W/(m$^2$·K) compared to only 3000 W/(m$^2$·K) for silicon. This also gives possibility for reduction of common mass and size of heat exchange equipment in two times.

**KEYWORDS**

Carbon nanotubes, heat exchange enhancement, CVD, PECVD, microscale heat transfer.

A problem of heat dissipation in electronic devices plays a key role for miniaturization of equipment and reducing of price of cooling systems nowadays. Microscale heat pipes and microscale heat transfer investigations are able to improve capability of heat dissipation in modern notebooks, handheld computers, smartphones and other type of stationary and mobile communication and computer equipment [1, 2].

Carbon nanotubes with unique physical properties can be useful for intensification of heat transfer in micro- and macroscale devices both. Another alternative is using of so called nanoliquids, dispersions of nanoscale particles in heat transfer liquid.

Carbon nanotubes coating described in [3] provides the unique opportunity to obtain coating by paint-like technology, namely by using of immerse solution of CNT and dried cycle. In this case it was possible to obtain CNT coating on complicate surface and low thermal resistance after 6–7 coating cycles. As result, so-called Dip-coating process can enhance thermal resistance by 8–10% in case of random oriented CNT. Possible problem of this technology is low mechanical stability of coating (depends on solvent), and low quality of thermal contact between surface and CNT.

For most critical application when dissipation of large heat fluxes is necessary another technology of CVD growth of CNT can be recommended. By CVD technology we can obtain more chemical stable CNT coating from oriented or random CNT with excellent heat contact with "hot" surface. That can improve heat dissipation in 10 or (in special cases) 70–80 times for example after CVD deposition of CNT on silicon surface. CVD technology also provides a possibility to obtain coating in complicate surface. But CVD process for CNT coating has very high potential and gives excellent possibility, by using of PECVD (plasma enhanced CVD) we can obtain DLC (diamond like coating) with unique heat conductivity of surface and than obtain CNT "radiator" for improve conductive and radiation heat transfer of surfaces as we need.

Typical surfaces that we can obtain by CVD process in our equipment is shown at figs. 1, 2 [4].

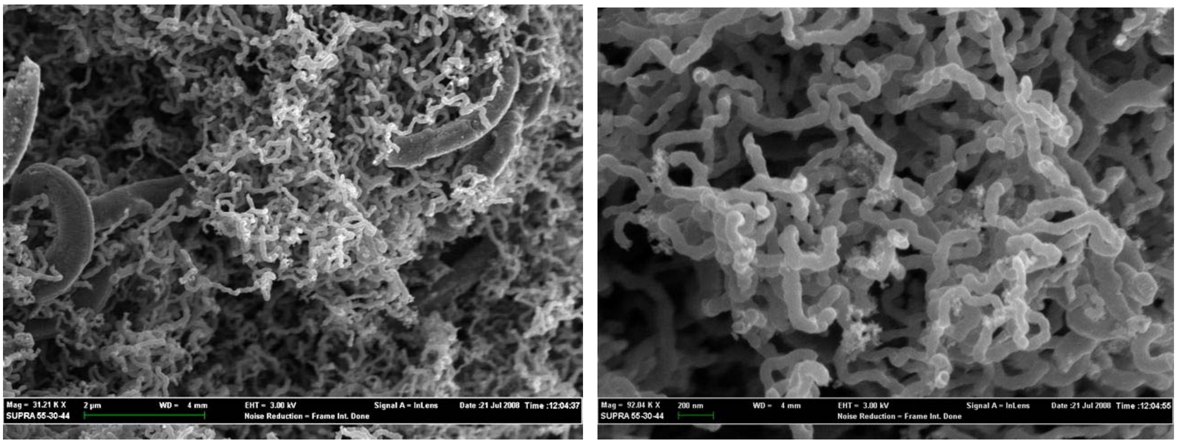


Fig. 1. Homogenous multiwall CNTs (random) on stainless steel surface

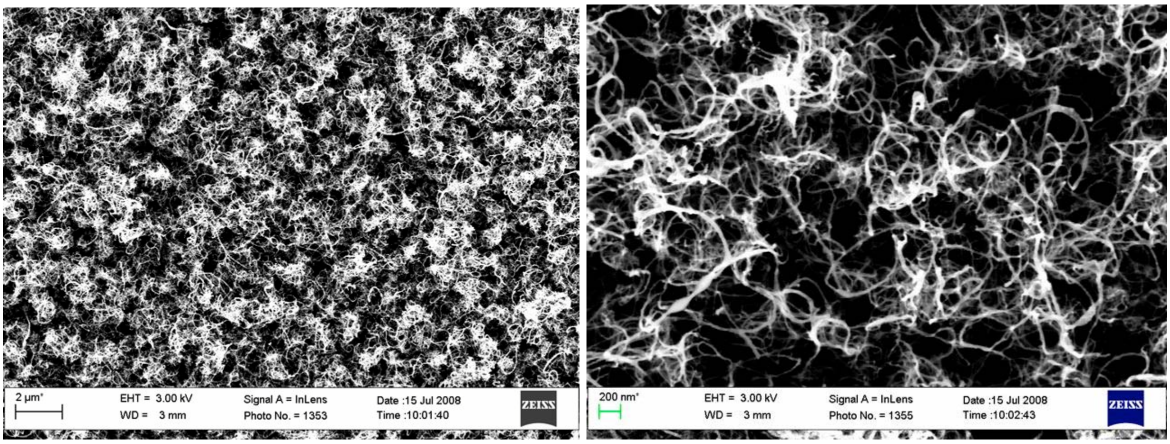


Fig. 2. Homogeneous single-wall CNTs (random) on silicon surface

Different type of CVD coating (Figs. 1–3) demonstrates good thermal properties and can be extremely useful for different applications. It also possible to improve heat dissipation by applying electrical field to this surface (nanoscale “electrical” wind) for conductive heat fluxes or by using of evaporation of distilled water from such surfaces. Another possibility under design is internal coating of heat pipes and study of nanoscale heat transfer on superconductive CNT or research of hydrophilic properties of CNT and CNT coating. Our experiments show possibility to using CNT as a part of thermoelectric cooler for microscale devices (some experiments in this area now in progress). Both technologies (direct CVD growth of CNT on surface and paint-like CNT coating, Table 1) can be used for air and water cooling devices.

Experimental research includes CNT coating on Si and stainless steel samples preparation and their study by electron microscopy and Raman spectroscopy for testing and characterization of CNT type (SWNT, MWNT, alignments etc.), and also a design of special test unit for study of heat flow rate from CNT enhanced surface (flat or micro channel surface) to environment is necessary.

Key laboratory equipment includes equipment for carbon nanotubes growth (CVD and PECVD, our own design), Raman spectrometer Nexus 550 (Thermo Nicolet), scanning electron microscopy Supra55 (Carl Zeiss) with microanalysis system INCA 350 (Oxford Instruments), transparent microscopy unit EMV-100, VIS fiber optic and IR Fourier spectrometers (Ocean Optics, Thermo, etc.), systems for thermal analysis and TGA, thermograph unit IR SnapShot 310.

Our research is focused on developing of a novel technology to produce highly boiling-efficient structures on heat exchanger surfaces. Advanced fabrication CVD technology was used to create ordered and disordered CNT coating with nanoscale pores.

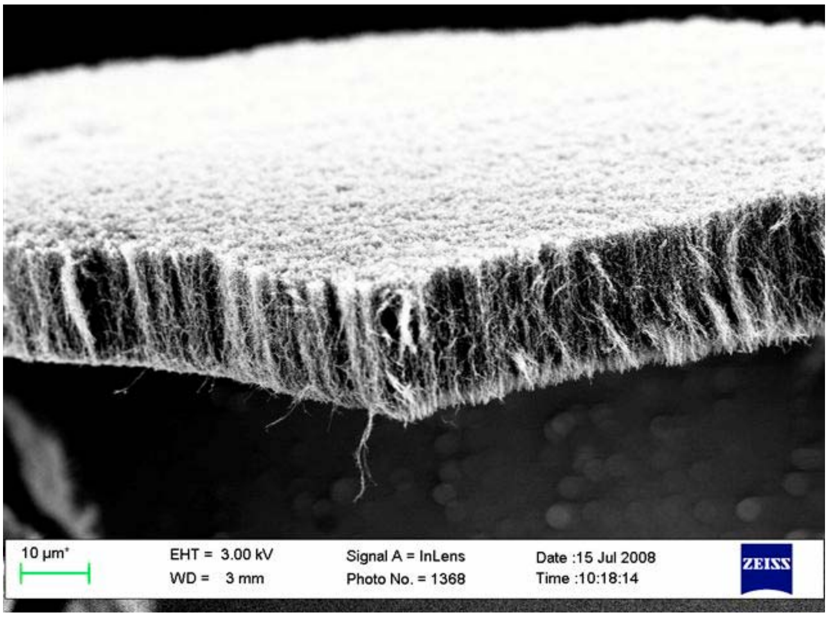


Fig. 3. Single wall carbon nanotubes on silicon surface

Table 1. Comparison between different CNT coating technology

| Properties | CNT DIP-coating | CNT CVD |
|---|---|---|
| CNT type | SWNT or MWNT or Carbon fibers | SWNT or MWNT or Carbon fibers |
| CNT structure | random or semi oriented | random or align |
| CNT lengths | 3–10 mkm | 0.2–10 mkm |
| CNT growth | indirectly | Directly |
| CNT density (per $mm^2$) | $2–9 \cdot 10^{10}$ | Up to $2.5 \cdot 10^{15}$ |
| CNT-surface heat contact | good | excellent |
| Electrical conductivity | middle | High |
| Mechanical stability | low | excellent |
| Heat exchange rate | 2–4 time | 4–100 time |
| Type of surface | metal | metal, semiconductor, glass |
| Internal surface coating | impossible | Possible |
| Electrochemical surface modification | impossible | Possible |
| Electrostatic stability (adhesion under electric field) | low | High |
| Fictionalization of surface | impossible | Possible |
| Coating equipment price | low | Middle |
| Coating material price | high | Low |
| Water resistivity (moisture stability) | low | high (good for water cooling devices) |

Study and characterization of microscale heat exchange of CNT based surfaces show that this technology is very attractive for microchannels heat exchanger and heat pipes. Typical heat flux can reach 0.8–1.2 $MW/m^2$ with typical CNT thermal conductivity equal to 1800–3000 W/(m·K) near room temperature. Tests, based on study of heat exchange of hot wire covered with nonalignment CNT of 0.9–1.2 nm diameter have showed the increasing of heat exchange rate more than five times and can increase up to 18000 $W/(m^2 \cdot K)$ compared to only 3000 $W/(m^2 \cdot K)$ for silicon.

The major goals of our current research are development of a new technology of creating of CNT-based coatings with low thermal resistance for complicate internal and external surfaces, study of heat and mass transfer phenomena in CNT based surface with different forms of CNT-based coating.

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