論 文 の 内 容 の 要 旨

論文題目　Thermal conductance of thin films composed of hetero nanotubes based on single-walled CNT
(単層CNTを元にしたヘテロナノチューブ薄膜の熱コンダクタンス)

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Carbon nanotube has (CNT) been one of the centers of nanomaterials since discovered by Iijima. Due to the attractive mechanics, optics, electronics and thermotics properties, carbon nanotube and assembles have been extensively investigated for the massive potential applications. Inherited from graphene, carbon nanotube possesses significant thermal conductivity along the axial direction, thus its probable prospects for thermal interface material has drown the attention of researchers and engineers. Besides, the possibility of synthesizing high-quality carbon nanotube and tailoring technique — designed structure, chemically doping, etc. — lead the development in carbon nanotube related researches one step further.

Carbon nanotube can be tailored in structure, forming films, mats, array with required length, thickness, and volume fraction. However, the limitation of carbon nanotube assemble application is obvious: in all carbon nanotube assemble, they tend to aggregate or forming bundles because of the van der Waals interaction. This contact is believed to suppress the high thermal conductivity individual carbon nanotube process, while the electrical properties has not been affected. Beside direct use, carbon nanotube could be filled into other materials like epoxy to as filling material to alter the thermal property. Yet to avoid aggregation, proper surface functionalization should be applied and which cause change to the perfect structure of carbon nanotube. Neither of the ways can take the full advantage of carbon nanotube.

Therefore, this thesis attempts to uncover the structure dependent thermal conductivity of carbon nanotube and propose a possible way to tailor carbon nanotube-based materials.

To study the structural dependent thermal transport property of carbon nanotube, a micro thermometer compatible with transmission electron microscope (TEM) has been fabricated. High quality single-walled carbon nanotube (SWCNT) can be transferred to micro thermometer with the detailed structure identified by scanning electron microscope (SEM) and TEM. The thermal conductivity of three carbon nanotube bundles with different sizes have been studied. The contact resistance between carbon nanotube and micro thermometer are ignored because of the large contact area. Geometry of the bundle samples are determined by SEM observation and calculation. The effective thermal conductivity of the three samples show a typical temperature dependent, that is increase with temperature and reach maximum at around room temperature. By plotting the thermal conductivity against bundle size, the structure dependent has been clearly observed. Compared with isolated carbon nanotube, thermal conductivity of bundle decreases with the bundle size increases. The decrease rate is changing from slow to fast and become slow again. For small bundle size like two, thermal conductivity is quite high and comparable to that of isolated carbon nanotube. However, the larger the size of the bundles, the lower its effective thermal conductivity. The quantitative study that thermal conductivity decrease logarithmically with the bundle size is further expanded with consideration of the newly added three samples. The intertube interaction is experimentally proved to degenerate thermal conductivity of carbon nanotube.

Van der Waals heterostructure (vdWH) is attracting vase attention recently. Without lattice matching and chemical bond, heterostructure has made it possible to combine different material together. Therefore, the relative researches started from 2-dimensional (2D) nanomaterials and quickly spread to 1-dimentional (1D) and even integrated dimensional materials. Compared with the systematic study on 2D vdWH, 1D vdWH is barely studied up to now. Owing to the development in 1D vdWH synthesis, high quality 1D heterostructure based on SWCNT can be synthesized by normal chemical vapor deposition (CVD) method.

In this these, 1D hetero nanotube based film will be synthesized by CVD method and the thermal property will be investigated with a contact-free steady-state infrared (IR) thermography method. The templates used are SWCNT films prepared by the aerosol CVD synthesis method with variable transparency from 52 % to 92 %. With the SWCNT films as a template, the heterostructured films were prepared by CVD, which can produce conformal and highly-crystalline BNNTs. Then, a contact-free steady-state infrared (IR) thermography measurement was used to investigate the in-plane sheet thermal conductance of the as-synthesized SWCNT-BNNT films. The results indicate the sheet thermal conductance of SWCNT-BNNT heterostructure films are 18524.1140 ± 2718.7684 nW/K, 14713.5110 ± 1588.2233 nW/K, 9146.2500 ± 1265.3946 nW/K, 6410.2564 ± 1964.9838 nW/K, 5892.3395 ± 1727.4211 nW/K at room temperature synthesized on SWCNT film with transparency of 53%, 62%, 72%, 87% and 92%, respectively. Compared with annealed SWCNT film of the same transparency, the increase are 23%, 44%, 53%, 80% respectively. Besides the thermal property, electrical, mechanical and thermoelectrical properties have been discussed together. A concise model is put forward to explain the thermal transport mechanism in the hetero film. The findings in previous structural dependent thermal conductivity also shed some light on the discussion of phonon transport in heterostructure film. From the experiment result, the heterostructure film shows better mechanical strength originated from BNNT and satisfying electrical conductance inherited form SWCNT.

In nano-scale, micro thermometer is fabricated and the structure dependent thermal conductivity of SWCNT is investigated; in macro-scale, a quick and handy method is presented here to measure the sheet thermal conductance of 1D heterostructure nanotube based thin films. Therefore, the clear relationship of the thermal conductivity of carbon nanotube and its nanoscale structure can help to design the thermal conductance of carbon nanotube thin films. This study also fills the gap in the study of 1D vdW heterostructure material up to now and may cast new light on following works in tailoring vdW heterostructure with new properties.