Carbon Nanotube-Metal Nanoparticle Heterostructures

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ABSTRACT

Carbon nanotubes (CNTs) decorated with gold nanoparticles are attractive nanoscale heterostructures, which hold strong potential for biomedical and sensing applications. In this regard, the effects of nanoparticles on original properties of CNTs are important to understand but are rarely studied. Herein, we report the nucleation of gold nanoparticles onto CNTs and studied the effects of these nanoparticles on the thermal conductivity of the hybrid through Raman spectroscopy. Knowledge of this aspect could enable the potential applications of these heterostructures as biomedical and sensing device.

Keywords: carbon nanotubes, nanoparticles, heterostructure, Raman spectroscopy, thermal conductivity

1 INTRODUCTION

Drug delivery and sensing via multifunctional nanostructures and nanocomposites using 1-D nanostructures decorated with nanoparticles are of interest [1-4]. Such heterostructured configurations can lead to high surface area substrates and multifunctionality [5]. In this regard, it is also critical to study effects of nanoparticles decoration on the electronic and thermal properties of 1-D structures such as carbon nanotubes (CNTs) [6-8]. We report the nucleation of Au nanoparticles on CNTs and study of their thermal conductivity. The approach to measure thermal conductivity employed Raman microscopy [9].

2 EXPERIMENTAL

CNTs were synthesized by chemical vapor deposition (CVD) technique using ferrocene as catalysts and xylenes as the carbon source at the ambient pressure [10]. The reaction was performed in H_2 atmosphere balanced with Ar at 675 °C for 2 h. As-produced CNTs were dispersed in ethanol. Gold nanoparticles were directly nucleated on CNTs using $HAuCl_4$ (5×10^{-3} M) as metal sources and $NaBH_4$ as reducing agent. Heterostructures were further dispersed onto silicon wafer (~0.25 cm^2). Raman spectroscopy characterizations were conducted at 20X and 785 nm laser. The integral time and co-addition were set as 10 and 2, respectively.

3 RESULTS AND DISCUSSION

Figure 1 shows the concept of thermal conductivity measurement using Raman spectroscopy [11]. The substrate is heated due to the illuminating laser and heat is gradually dissipated away from the laser point. In order to determine the laser spot size, we focused on a reflective mirror and estimated the diameter of laser at 20X is around 5 µm (Figure 1A).

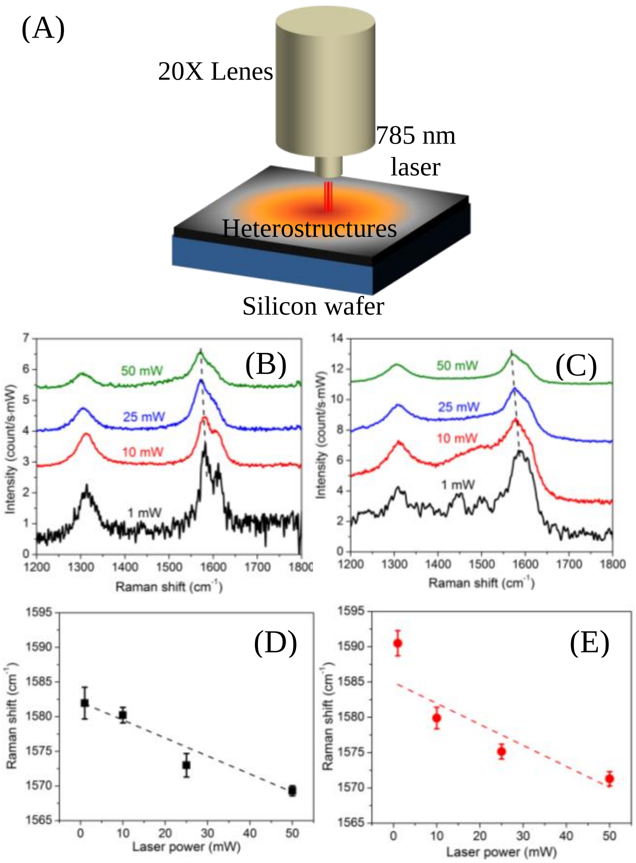

Figure 1. (A) Schematic illustration of Raman set-up for measuring thermal conductivity of heterostructures and raw-CNTs. Raman spectrum of samples collected at different laser powers for (B) pristine CNTs and (C) CNT-Au heterostructures. Shift of G band at different laser power for (D) pristine CNTs and (E) CNT-Au nanoparticles heterostructures,

Raman spectra were collected for as-produced CNTs and CNT-Au nanoparticles heterostructures at 1 mW, 10 mW, 25 mW, and 50 mW laser powers (Figure 1B-E). Dotted lines were drawn to show the shift of G-band toward lower Raman shift at high laser power (Figure 1B and C). It has been well studied that G-band shift is linearly proportional to laser power [12,13]. Thus, linear fittings (slope: m_1) were conducted as showing in Figures 1D, 1E, and Table 1. This allowed for deriving G band position as a function of laser power and assuming temperature coefficient (m_2) to be ~0.028 cm^{-1}/K [13,14]. These results and assumptions further allowed for calculating thermal conductivity using the following equation [15]:

$$K=Sm_2/(2\pi t m_1) \quad (1)$$

Where S is a constant related to diameter of laser spot and t is the thickness of film as estimated to be around 3 μm. Since S is related to spot size and configuration of Raman spectroscopy, a plot between estimated thermal conductivity and S is shown in Figure 2. The calculated thermal conductivity values are shown in Table 1 by assuming S is 2.97 (laser spot size is 5 μm). It is clear that type of nanoparticles could affect the thermal conductivity as the decoration of gold accounted for 13% decrease in K. This could be attributed to the fact having nanoparticle decorations on CNTs led to significant phonon scattering centers and thus hindering phonon transport across the CNT films. This precise decrement of thermal conductivity could be useful for fabricating thermally-stimulated biomedical devices.

Table 1. Linear fitting of Raman shift at different laser power and calculated thermal conductivity.

Sample	Slope ($cm^{-1}\cdot mW^{-1}$)	Intercept (cm^{-1})	R^2	Thermal conductivity (W/m-K)
CNTs	-0.26	1582.1	0.95	17.1
CNT-Au	-0.30	1585.9	0.70	14.9

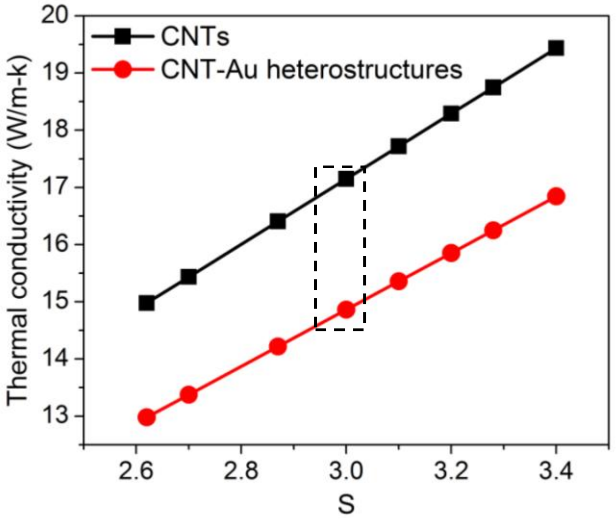

Figure 2. Effects of coefficient S on thermal conductivity of both CNTs and CNT-Au nanoparticles heterostructures.

CONCLUSIONS

CNTs were decorated with Au nanoparticles using a direct nucleation method. Effects of nanoparticles decoration on thermal properties of CNTs were studied using micro-Raman spectroscopic characterization. Thermal conductivity could be derived from the shift of G band at different illumination laser power. Results showed that nucleation of Au nanoparticles decreased the thermal conductivity for ~13%.

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