Optial properties of align carbon nanotubes film

Weibiao Wang (王维彪), Yuxue Xia (夏玉学), Ming Chen (陈 明), Jingqiu Liang (梁静秋), Lili Liu (刘丽丽), Song Chen (陈 松), and Da Lei (雷 达)

Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033

The optical properties of carbon nanotubes are studied. Align carbon nanotubes films were synthesized by chemical vapour deposition method in our lab. The diameter of carbon nanotube is about 20–30nm. The amorphous carbon impurities in align carbon nanotubes film were removed by a series of deal with processes. Carbon nanotubes were examined up by using scanning electron microscope, transmission electron microscope and Raman spectrum.The reflected spectrum, transmission spectrum and absorption were measured. Results show that carbon nanotubes have strong absorption from visible region to mid-infrared (IR) region. Photoluminescence spectra of carbon naotubes film were studied at 488, 632.8, and 1060 nm excited laser wavelength. Results show sthat there are nonlinear processes in luminescence of carbon nanotubes under ultrafast laser excitation (1064 nm, 60 ps) conditions. A broad photoluminescence peak was location at 1.6 eV (about 768 nm), this phenomenon was considered to relate to van Hove singularities, and was a three-photon-absorption process.

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Since the first report of discovery of multiwalled carbon nanotubes (MCNTs) by Iijima in 1991[1], canbon nanotubes have drawn great attention throughout the world due to their particular microstructures, unique properties and great potential applications in many fields. Lots of researchers have studied optical and electronic properties of carbon nanotubes except for its other properties such as hydrogen storage, mechanical, field emission performance, electrochemical behaviors and chemical properties of carbon nanotubes. Considering carbon nanotubes have unique microstructure and electron structure, some researcher studied luminescence property of carbon nanotubes and hope it has some potential application in photoelectron field[2−4]. Another research work, Bonard research group[5] observed luminescence phenomena during studying field emission of carbon nanotubes. This phenomena reveal a possible for photoluminescence(PL). In our research works about process of photon-electrical transition and photon-thermo transition, some optical properties of MCNTs were studied. The aims were to develop new optical-electrical materials and optical-thermo-materials. In the paper, the some optical phenomena of MCNTs were reported.

Synthesis ways of carbon nanotubes are saw everywhere[6,7]. In our works, synthesis of MCNTs film was solved in high temperature furnace by using C_2H_2/H_2+N_2 and ferrocene catalyst in our lab. Growth temperature of carbon tubes was about 1000 K. The substrates were quartz plates. After synthesis, align MCNTs film was purified and dispersed, impurities on these align MCNTs film were cleaned in hot vitriol and nitric mixed acid solution. Then them were dispersed in alcohol solution by ultrasonic. Finally, they were baked in vacuum oven at 400 K. Most of optical properties measurement is solved in the key lab of excited state process in physics, the Chinese Academy of Sciences. Linear absorption measurements in the visible region and near- to mid-infrared (IR) region were carried out with SHIMADZU UV-3101PC spectrophotometer. Photoluminescence measurements were carried out with a focus beam from a Nd:YAG laser operating at 1.064 μm with a pulse width of 60 ps and a repetition rate of 10 Hz. The output peak power was varied through a range of 0.1–6GW/cm^2.

The scanning electron microscope (SEM) and transmission electron microscope (TEM) images of carbon nanotubes are shown in Fig. 1, the SEM image (Fig. 1(a)) reveals that a align MCNT film has been made after growth. A litter impurity also be seen in the top of align carbon nanotubes film. These impurities will be removed in purification processes. The TEM image of pure carbon nanotubes after primary purification are shown in Fig. 1(b). From these images, the diameters of multiwalls carbon nanotubes are about 20–30nm.

The Raman spectra of MCNT film were shown in Fig. 2, excited wavelength was 488 nm of Ar^+ ions laser. As shown in Fig. 2, a weak broad peak (normally called D-band) can be seen at 1398 cm^{-1}, which is due to the disorder-induced photons.The peaks near 1590 cm^{-1} in high frequency region (normally called G-band) due to the tangential C-C stretching mode. The ratio of peak intensity of G-band to D-band (G/D value) is a good

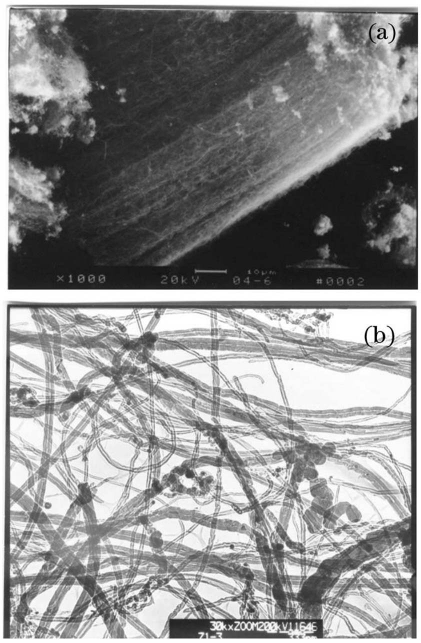

Fig. 1. SEM image (a) and TEM image (b) of MCNT.

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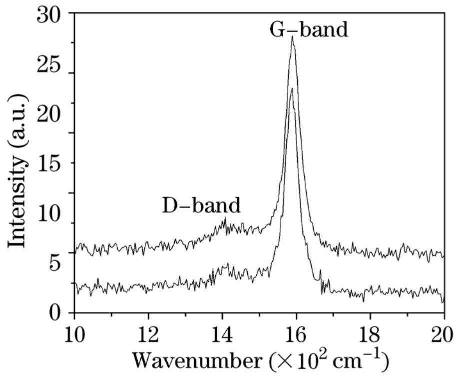

Fig. 2. Raman spectra of MCNT film.

index of multiwalls carbon nanotubes, it shows that carbon nanotube have higher graphitization degree.

Figure 3 shows the reflected spectrum of MCNT film. In the Fig. 3, From reflective spectrum of MCNTs film, it could be seen that it has higher reflective ratio in short wavelength region (≤500 nm), but it has very low reflective ratio in longer wavelength region to mid-IR region. Fiure. 4 shows the transmission spectrum of MCNT film. Result shows that MCNTs film has very low transmission ratio. Figure 5 shows a non-normalized absorption spectrum of MCNT film. Form these spectrum, it could be seen that most of light energy was absorbed by MCNTs film. These results illustrated that MCNTs film has strong light absorption power.

In our many MCNTs samples, almost of all have strong light absorption. As a part of research works on light

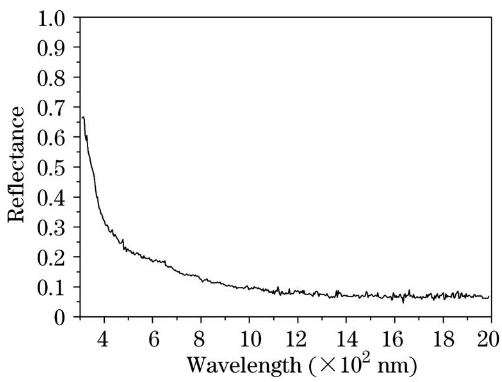

Fig. 3. The reflection of MCNT film.

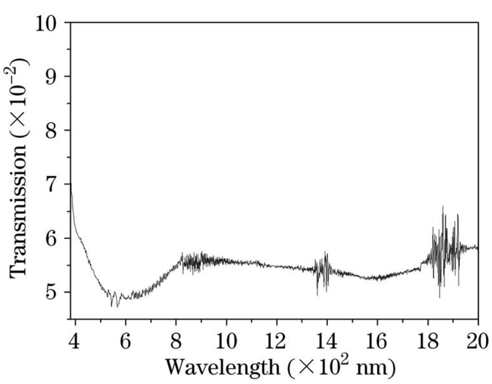

Fig. 4. The transmission of MCNT film.

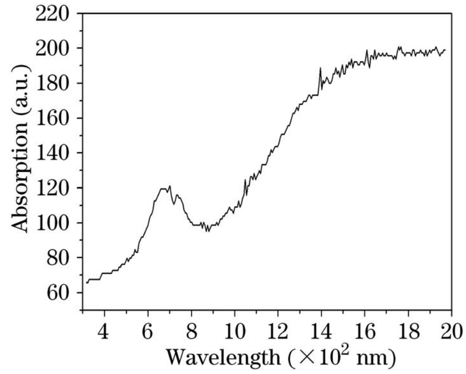

Fig. 5. Absorption of MCNT film.

absorption, we examined the luminescence of MCNTs at a series of excited laser such as 488, 632.8 and 1064 nm, however there are no luminescence phenomena observed at these general excited light. Even no luminescence was observed at 200 nm excited light. Considering influence of excited laser intensity, the pulse laser of 1064 nm with 60 ps was used to excite MCNTs to examine the nonlinear luminescence phenomenon. At about 2.8-GW/cm^2 excitation, the broad photoluminescence band (peak at about 768 nm, approximately 1.6 eV) was detected by spectrometer, as shown in Fig. 6, spectrum shape is very similar to that observed by Brannan *et al.*[11]. The result shows that only very small amount of energy is emitted as the way of light.

The nonlinear PL phenomenon was regarded as relating to van Hove singularities (VHS) in MCNTs by Brennan *et al.*[4], in their paper, this phenomenon suggested that the optical transitions involved a three photons absorption process, which is resonantly enhanced by the presence of VHS absorption. In three-photons absorption with an excitation energy of 1.16 eV (1064 nm), those intermediate levels are located at 1.16 and 2.33 eV, final level at 3.49 eV.

There were relative luminescence phenomenon in MCNTs, Bonard *et al.*[4] studied field emission-induced luminescence in MCNTs. They suggested that the luminescence was due to electronic transitions between energy levels at the tip that are participating in the field emission.

Although they explained luminescence phenomenon in carbon nanotubes, but to fully understand this nonlinear PL mechanism, it need more research evidences. Also, there are many problems to research such as energy

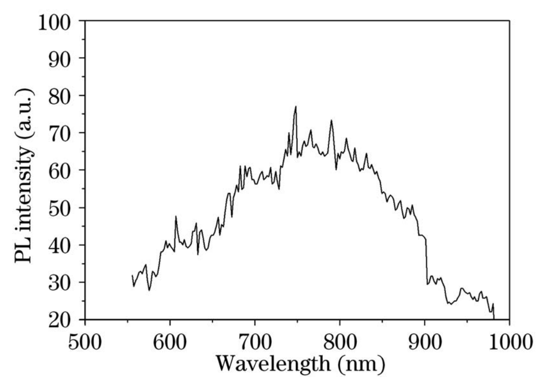

Fig. 6. Photoluminescence of MCNTs.

level distribution of MCNTs, van Hove singularities of MCNTs, PL decay and at different strong excitation power and different wavelengths, relation of nonlinear PL with field-emission-induced luminescence, and so on. All these will unveil yet another puzzling aspect of their fascinating properties.

Through these research works of MCNT film, MCNTs was a excellent light energy storage and transition material, it can transit optical energy into electrical energy and thermo-energy, and has some nonlinear optical applications. The more research works will be continually reported.

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