적외선 영역에서의 HgTe 나노입자 광전류 특성

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Photocurrent characteristics of close-packed HgTe nanoparticles in the infrared-wavelength range

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Abstract

Photocurrent spectrum, photoresponse, and I-V measurements were made for close-packed HgTe nanoparticles without organic capping materials to investigate their photocurrent characteristics in the infrared range. In absorption and photoluminescence (PL) spectra taken for the close-packed nanoparticles film, the wavelengths of exciton peaks was red-shifted, compared with organic capped HgTe nanoparticles dispersed in solution. This red-shift is caused by the lessening of the exciton binding energy. The I-V curvesand photoresponse for the close-packed nanoparticles film reveal their dark current and fast photoresponse with no current decay, respectively. The observation suggests that the HgTe nanoparticles are a very prospect material applicable for photodetectors in the whole IR range.

Key Words : HgTe, nanoparticle, Photocurrent, Infrared(IR), Photoluminescence(PL)

1. 서 론

Various semiconductor nanoparticles have been studied for their applications to optoelectronics including light-emitting diodes (LEDs) and photodetectors[1-2]. Most researches have been related tothe visible range operating devices based on CdSe, CdS, and CdTe nanoparticles, but few researches have been focused on the infrared (IR) range operating ones although the optoelectronics operating in the IR range are of crucial importance in the fields of the optical communications, medical applications, and IR image sensors.

HgTe nanoparticles exhibit their effective bandgap in the range of infrared wavelength due to the shrinkage of their size [3], although bulk HgTe has been known as semi-metal material with the bandgap of -0.13 eV at room temperature. The synthesis of a hybrid system of organic materials and HgTe nanoparticles and its photocurrent characteristics were reported previously in Ref. 4. Although the active wavelength of photocurrent in the hybrid system is controllable in the visible- and infrared-wavelength ranges, this system has shown slow photoresponse with current decay and instability of the organic materials. Moreover, photoexcited electrons may not transport in the hybrid system. In this study, in efforts to overcome these unwanted characteristics, optoelectronic properties of close-packed HgTe nanoparticles without organic capping materials are investigated.

2. 실 험

1-thioglycerol-capped HgTe nanoparticles were synthesized in aqueous solution by the colloidal method [3]. The HgTe nanoparticles powders were obtained by the centrifuge process after the addition of isopropyl alcohol. The HgTe nanoparticles powders were washed with methanol and acetone to remove the organic capping material of 1-thioglycerol. The synthesis of the HgTe nanoparticles was confirmed by high-resolution transmission electron microscope (HRTEM) and x-ray diffraction pattern. The close-packed HgTe nanopaticles film was fabricated by dropping HgTe nanoparticles re-dispersed in water on a Si/SiO_2(300nm) substrate on which two gold electrodes with a separation of 6μm were patterned. The optical properties of as-synthesized HgTe nanoparticles dispersed in water and close-packed HgTe nanoparticles dropped on a glass plate were examined with absorption and photoluminescence (PL) spectroscopies. The excitation source for PL was the 633nm-wavelength light from a HeNe laser. The excitation source for photocurrent measurement is light from a quartz-tungsten-halogen (QTH) lamp dispersed by a Traix 320 monochromator. All the measurements were performed under vacuum.

3. 결과 및 고찰

HRTEM image of the HgTe nanoparticles is shown in Fig. 1. The HRTEM image exhibits the regularly-ranged lattice arrays of the HgTe nanoparticles, revealing their high crystalline qualities. The average size of the particles is about 5nm in diameter.

In Fig. 2, the absorption and PL spectra of a close-packed nanoparticle film without the capping materials are compared with those of 1-thioglycerol capped HgTe nanoparticles dispersed in water. First of all, see the absorption and PL spectra of the capped HgTe nanoparticles. The strong exciton absorption and emission peaks are present in the near-IR range,

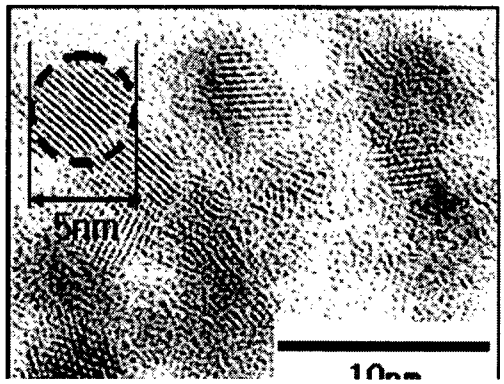

Fig 1. High-resolution transmission electron microsope(HRTEM) image of the synthesized HgTe nanoparticles

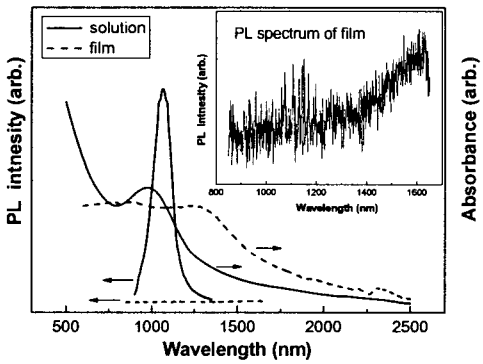

Fig 2. PL and absorption spectra of the capped HgTe nanoparticles in aqueous solution, and the close-packed nanopaticles film

and the wavelength difference between two exciton peaks is about 100nm. The wavelength difference is due to the Frank-Condon shift. Compared with the capped HgTe nanoparticles, the exciton peak in the absorption spectrum of the close-packed nanoparticle film is shifted to the longer wavelength range. For the PL spectrum of the close-packed HgTe nanoparticle, the PL emission is very weak in the range from 850 to 1650 nm. Nevertheless, in the inset of Fig. 2, the onset of the exciton peak is still seen around the wavelength of 1300 nm. The observation indicates that the exciton emission

peak is more significantly shifted and that the peak position is thereby out of the operating wavelength range of the Ge detector. The red-shift of the exciton peaks for the close-packed nanoparticle film may be caused by the Ostwald ripening originating from the absence of organic capping materials surrounding HgTe nanoparticles. Our previous study showed that the PL spectrum of the film fabricated with the 1-thioglycerol capped HgTe nanoparticles is nearly the same as that of the 1-thioglycerol capped HgTe nanoparticles dispersed in water [4]. For the close-packed HgTe nanoparticles without the capping materials, the electron wavefunction may overlap with that of adjacent nanoparticles weakening the quantum confinement effect, followed by lessening the exciton binding energy. This causes the red-shift of the exciton peaks in the absorption and PL spectra.

The photocurrent spectrum of the close-packed HgTe nanoparticles is compared in Fig. 3 with the conventional Ge photodetector. The excitation source is the light of a QTH lamp dispersed by a monochromator, and the spectrum of the Ge detector is calibrated by the wavelength-dependent quantum efficiency. The line shape of the photoresponse spectrum of the close-packed HgTe nanoparticles is very similarthat of Ge detector after calibration, indicating that the HgTe nanoparticles have a nearly flat photoresponse characterization in this wavelength range. The photocurrent measurement was performed at room temperature at a biased voltage of 1V and has no amplification. It can be concluded that the HgTe nanoparticle is a promising material applicable for the photodetector operating in the whole IR range even though this experiment was performed in the near IR range.

The current-voltage (I-V) curves for the close-packed HgTe nanoparticles in dark and under the illumiantion of 1100nm wavelength

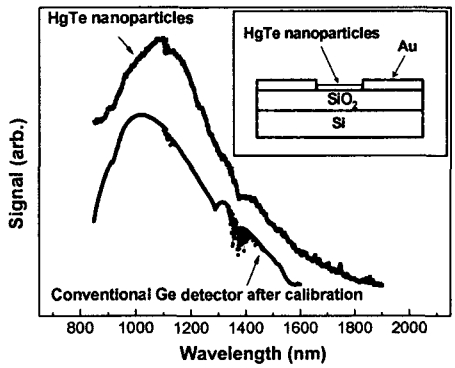

Fig 3. Photoresponse spectra of the close-packed HgTe nanoparticles compared with the conventional Ge photodetector in the IR range; inset shows the schematic of the fabricated structure for the photoresponse measurement.

light with less than 1mW/cm^2 in power are depicted in Fig. 3(a). The dark current is below several pA level. This magnitude is smaller by 10^3 times, compared with those of the 1-thioglycerol capped HgTe nanoparticles. The current is increased by about 3 orders of magnitude at a biased voltage of 3 V when the HgTe nanoparticles are exposed to the light. The I-V curves are nearly linear, so the contact between the HgTe particles and the gold metal is ohmic. This ohmic contact may be expected from the difference between the work function of gold and the electron affinity of the HgTe nanoparticles: the work function of gold is 5.1eV and the electron affinity of the HgTe nanoparticles is about 5.5eV. Figure 3(b) shows the evolution of the current when nanoparticles were under illumination of IR light at 1100nm for 30 sec and in the dark for 30 sec 3 times repeatedly at 3 V. The photoresponse is very rapid beyond the time resolution in the measurement system and the photocurrent level keeps stable during the repeated photoresponse measurement. The rapid photoresponse indicates that the photo-excited carriers transports in the

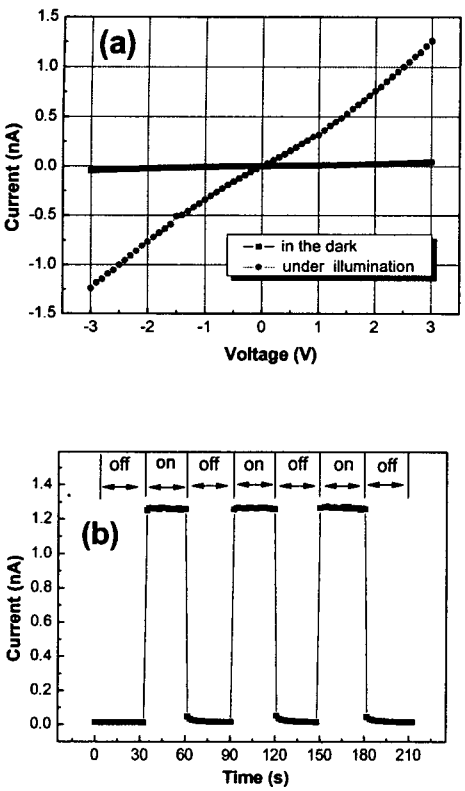

Fig 4. *I-V* curves (a) of the close-packed HgTe nanoparticles in the dark and under illumination photoresponse (b) for the time

extended states in the close-packed HgTe nanoparticles.

For the close-packed nanoparticle film, the magnitude of the dark current is smaller by 10^3 times, the photoresponse is much more rapid, and the photocurrent is more intensified in strength, compared with those of the 1-thioglycerol capped HgTe nanoparticles previously reported in Ref.4. These indicate that the photo-excited carriers transports in the extended states in the close-packed HgTe nanoparticles, that it helps the electron-hole pairs(EHPs) generated by photons separate and transport by tunnelling over the surface barrier of nanoparticle considering many nanoparticles based photodetectors have been in difficulties with breaking excitons to separate charges and transporting via nanoparticles by overcoming the quantum barriers of capping materials[2].The decrease in dark current by removal of the organic capping materials can make possible high sensitivity IR photodetector using HgTe nanoparticles.

4. 결 론

We fabricated the close-packed HgTe nanoparticles film in which the organic capping materials were removed. And the results such as low dark current, fast response time, current stability suggest that HgTe nanoparticle is a very prospect candidate material for the photodetector in the whole IR range

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