

Raman spectroscopy of CdTe/ZnTe quantum dot structures

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Semiconductor low-dimensional structures of CdTe quantum dots (QDs) embedded in ZnTe matrix have been investigated by micro-Raman spectroscopy. A reference ZnTe sample (without dots) was also studied for comparison. Both samples were grown by a molecular beam epitaxy technique on the *p*-type GaAs substrate. The Raman measurements have been performed at room temperature. The samples were excited by an Ar²⁺ laser of 514.5 nm wavelength. The Raman spectra have been recorded for different acquisition parameters of the measurement. For the reference and QD sample localized longitudinal (LO) phonons of 210 cm⁻¹ wavenumber associated with the ZnTe layer are observed. In the case of QD sample another broadband corresponding to the LO CdTe phonon related to the QD-layer appears at a wavenumber of 160 cm⁻¹. Such behaviour does not exhibit the Raman spectra of the reference sample. Thus the Raman measurements confirm the presence of CdTe layer of quantum dots in the investigated material. Additionally, Raman spectra for both samples exhibit tellurium-related peaks at wavenumbers around 120 cm⁻¹ and 140 cm⁻¹, significantly increasing with laser time exposure. It is shown that the peaks are associated with the formation of Te aggregates on the ZnTe surface due to the laser damage in the ZnTe layer.

Keywords: Raman spectroscopy, CdTe, ZnTe, quantum dot structures.

1. Introduction

Extensive studies have recently been carried out on semiconductor II–VI compounds due to a wide band gap of these materials and possibility to create optoelectronic devices on their base. Adding quantum dots (QDs) to such structures improves the efficiency of these devices because of a three-dimensional confinement potential for the charge carriers captured in QDs.

Zinc telluride (ZnTe) is a direct band gap semiconductor compound of room temperature energy gap equal to 2.26 eV [1]. For this it has been long considered as

a very promising material for green optoelectronics. With respect to this application, the CdTe/ZnTe quantum dot system has been recently extensively studied, but the large lattice mismatch ($\sim 7\%$) makes it very difficult to grow CdTe/ZnTe structures of high quality [2].

Raman technique has been proved to be a useful tool for structural characterization of various crystals [3–5]. It can provide information on the molecular vibration, microscopic disorder and residual stress in the material as well as on the material crystallinity. It has been also commonly accepted that Raman spectroscopy is a nondestructive technique. However in the case of II–VI compounds it has been shown that the exciting laser power density used in Raman measurements contributes to the local heating of the structure leading to its damage [6, 7]. In present paper we focus on the investigations of semiconductor CdTe/ZnTe quantum-dot system using micro-Raman spectroscopy. Structural properties of the system are analyzed in terms of obtained results and it is shown how laser exposure time affects the surface of the studied samples leading to its damage. The performed analysis might shed light on the origin of the damage in the II–VI compounds, which is still unclear.

2. Experimental details

The objects of investigations are two samples processed by a molecular beam epitaxy method: a sample with self-assembled quantum dots (SAQDs) and a reference sample without the dots. The reference sample consists of $3\ \mu\text{m}$ thick p^+ -type ZnTe:N buffer deposited on the p -type GaAs substrate, $1\ \mu\text{m}$ undoped ZnTe and $0.3\ \mu\text{m}$ of undoped ZnTe cap. The QD sample has the same layer structure, but additionally it contains a layer with CdTe SAQDs. The dots were grown in the atomic layer epitaxy growth mode by deposition of six monolayers (MLs) of CdTe. The process of QD formation was induced by covering the CdTe layers with an amorphous tellurium layer and its subsequent thermal desorption [8]. The layer structure of the QD sample is depicted in Fig. 1. The micro-Raman measurements were performed at room temperature with the help of the T64000 Jobin–Yvon spectrometer configured in backscattering geome-

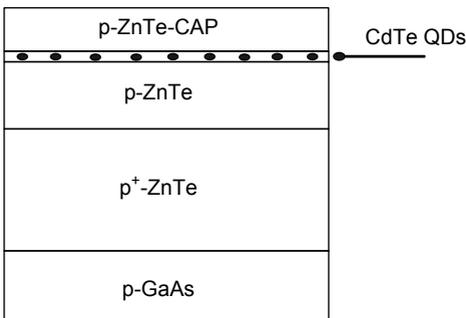


Fig. 1. The layer structure of CdTe/ZnTe quantum dot sample.

try and the triple subtractive mode of operation equipped with a multichannel CCD camera (illuminated spot $\sim 1 \mu\text{m}$). The samples were excited by an Ar^{2+} laser working at a wavelength of 514.5 nm. The Raman spectra were recorded at constant laser power, for different time of the laser irradiation exposure.

3. Results and discussion

Micro-Raman spectroscopy technique has been applied to study material and phonon properties of investigated structures, subjected to the laser damage. Results of Raman measurements for the QD- and reference sample are shown in Fig. 2 for comparison. Both spectra were recorded at the same measurement conditions. The plot in the case of a QD sample has been multiplied by three in order to clarify the comparison of its Raman spectrum with respect to the reference sample.

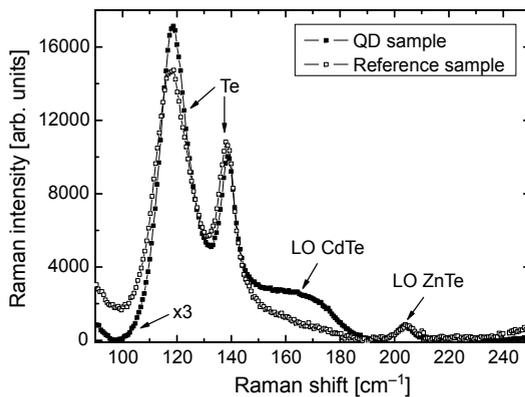


Fig. 2. Raman spectra for the QD- (6 MLs of CdTe) and reference sample measured at room temperature for the laser power equal to 12 mW.

The Raman spectra for both samples are dominated by two tellurium-related bands at wavenumbers around 120 and 140 cm^{-1} and a peak observed for the wavenumber of 205 cm^{-1} which has been assigned to localized longitudinal (LO) phonon mode associated with the ZnTe layer [9]. The presence of CdTe QD layer in the QD sample reveals a broadband at a wavenumber of 160 cm^{-1} close to the LO CdTe phonon mode [9]. Such a band does not exhibit the Raman spectra of the reference sample. The broadness of the band indicates on both nonhomogeneous distribution and size of QDs resulting in a distribution of phonon modes related to QDs. It has to be pointed out however that the QD related peak is observed solely at certain measurement conditions. In order to explain the issue, the Raman spectra of the QD sample recorded for different time of a laser exposure presented in Fig. 3 are analyzed as follows.

Performing Raman experiments for different time of a laser exposure it has been noticed that for a short time of 12 s the LO CdTe phonon peak is missing on the Raman

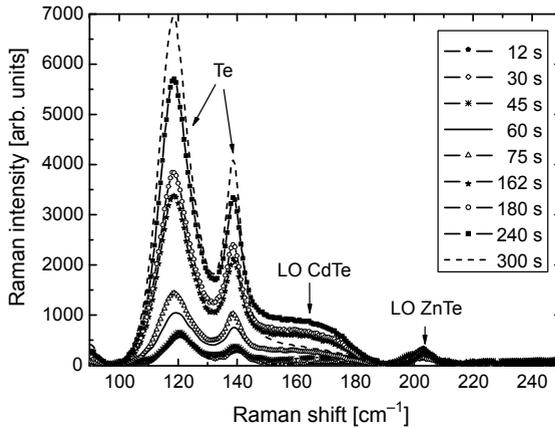


Fig. 3. Raman spectra of the QD sample (6 MLs of CdTe) recorded for different time of a laser exposure from 12 to 300 s. The laser power was equal to 12 mW.

spectrum of the QD sample. It appears and becomes even better visible when the time duration of a laser irradiation increases (*cf.* Fig. 3). Simultaneously its amplitude increases as well as the amplitude of the LO ZnTe phonon peak and Te-related Raman peaks. However for long enough time of a laser exposure (above 240 s) the LO CdTe phonon peak disappears (*cf.* Fig. 3) whereas that associated with Te aggregates becomes pronounced. Above behaviour can be explained assuming laser damage of the studied layers [10]. The value of the absorption coefficient for ZnTe at an excitation wavelength of 514 nm is equal around $5 \times 10^4 \text{ cm}^{-1}$ [11]. Based on the Lambert–Beer–Bouguer law, the penetration depth of a laser beam can be estimated. For the investigated structure it was found to be equal to 0.2 μm . Hence for the short time of exposure the laser beam is absorbed in the ZnTe cap layer so the Raman spectrum does not exhibit LO CdTe mode. However due to the surface damage accompanying laser irradiation, light beam penetrates the structure the deeper, the longer is the time of a laser exposure. As a consequence the laser beam steeply reaches following layers of the structure so that the Raman signal related to CdTe appears, its intensity increases, then decreases and eventually, once the laser beam reaches the bottom of the CdTe layer, vanishes. As for the Te-related peaks, the bigger damage, the higher their amplitudes implying that rising damage is followed by increasing amount of crystalline Te aggregates created on the surface.

Hence micro-Raman measurements confirm the presence of CdTe layer of quantum dots in the investigated material and a surface damage rising with increasing time of a laser exposure.

4. Conclusions

The CdTe/ZnTe quantum dot structure has been exposed to Raman measurements to analyze the surface composition and phonon properties of investigated material.

The reference sample, without the dots, was also studied for comparison. Raman spectroscopy yielded valuable information on the phonon spectrum of QD structures. A broadband corresponding to the LO CdTe phonon related to the QD-layer appears at a wavenumber of 160 cm^{-1} in the case of sample with QDs and it has not been observed in the case of the reference sample. Therefore the measurements proved the presence of CdTe layer of quantum dots in the investigated material. Raman spectra of both the reference and QD sample reveal strong tellurium bands, which appear because of the laser damage in the ZnTe layer followed by the formation of Te aggregates on the ZnTe surface. The damage-degree depends on the laser exposure time of the measurement. Results of our investigations show that the surface damage of the studied CdTe QDs in ZnTe matrix is similar to the damage observed for CdTe, ZnTe and CdZnTe single crystals/epilayers.

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