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Atomic Scale Characterization of HgTe/CdTe Superlattices Using STEM Z-Contrast Imaging and VEELS

Lianfeng Fu,* Nigel D. Browning,*,** Hye-son Jung,*** and Christoph Grein***

* Department of Chemical Engineering and Materials Science, University of California at Davis, Davis, CA 95616 USA
** National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 USA
*** EPIR Technologies Inc., 590 Territorial Drive, Bolingbrook, IL 60440 USA

There has been extensive studies performed in II-VI semiconductor materials for both the fundamental physics and their potential applications in light emitters, chemical sensors, UV coatings, medicines, etc [1]. Among the II-VI//II-VI quantum structure systems, HgTe/CdTe superlattices (SLs) are of particular interest in the field of long wavelength infrared detector due to their widely variable band-gaps [2]. It is known that the electrical and infrared detector properties of HgTe/CdTe SLs are strongly dependent on the growth quality of HgTe/CdTe heterointerfaces and the band-gaps of SLs. Furthermore, the band-gaps of HgTe/CdTe SLs are related to the thickness of individual layers. Therefore, a complete characterization of HgTe/CdTe heterointerfaces and an exact knowledge of the thickness variation in SLs and its relationship with the band-gaps are important to fully develop HgTe/CdTe SLs for infrared detector devices.

In this study, we have used the scanning transmission electron microscopy (STEM) high angle annular-dark-field (HAADF) Z-contrast imaging and valence electron energy loss spectroscopy (VEELS) techniques to characterize the HgTe/CdTe SL heterointerfaces. It is well known that Z-contrast imaging in STEM can easily identify the hetero-interfaces with different compositions [3-5]. The use of VEELS to determine the band gap and obtain other electronic information is also well established [6]. Therefore, the conjunction of Z-contrast imaging and VEELS analysis makes a very powerful technique for the interfacial characterization of SLs.

The HgTe/CdTe SLs were grown on CdTe/Si(211)B substrates using Molecular Beam Epitaxy (MBE) methods in EPIR Tech. STEM samples were prepared in the cross-sectional geometry using conventional cross-section sample preparation processes. The STEM Z-contrast imaging and VEELS experiments were performed in NCEM, LBNL using a 200 kV Schottky field-emission gun (FEG) FEI Tecnai F20 UT STEM/TEM. The microscope is equipped with a double focusing Wien filter acting as a monochromator directly below the field-emission gun. This configuration in combination with a high-resolution Gatan Imaging Filter (GIF) system allows for a high energy resolution of 0.18 eV or better, which makes accurate band gap measurement possible.

The results of STEM Z-contrast imaging of the HgTe/CdTe SLs show that the individual SL layers are well-defined and uniformly grown. The 200 periods of a HgTe/CdTe SL were identified to be epitaxially grown on a CdTe buffer layer with the orientation of $SL_{(211)}$ / $CdTe_{(211)}$ / $Si_{(211)}$, as shown in Figure 1(a) and 1(b). The thickness of CdTe buffer layer was determined to be 7.0 μm and that of HgTe/CdTe SLs as 1.8 μm, which matches well with XRD data. The layer thicknesses d_{HgTe}/d_{CdTe} of one sample near the substrate are determined to be 47±2 Å /41 ±2Å. However, the thickness d_{HgTe}/d_{CdTe} near the surface are slightly different, namely 51±2 Å /41 ±2 Å. VEELS analysis based on the 41 Å CdTe layer reveals that its band gap is about 1.65eV, as shown in Figure 2, which agrees with band structure calculations. Band gap measurements of individual HgTe layer with different thickness will be discussed.

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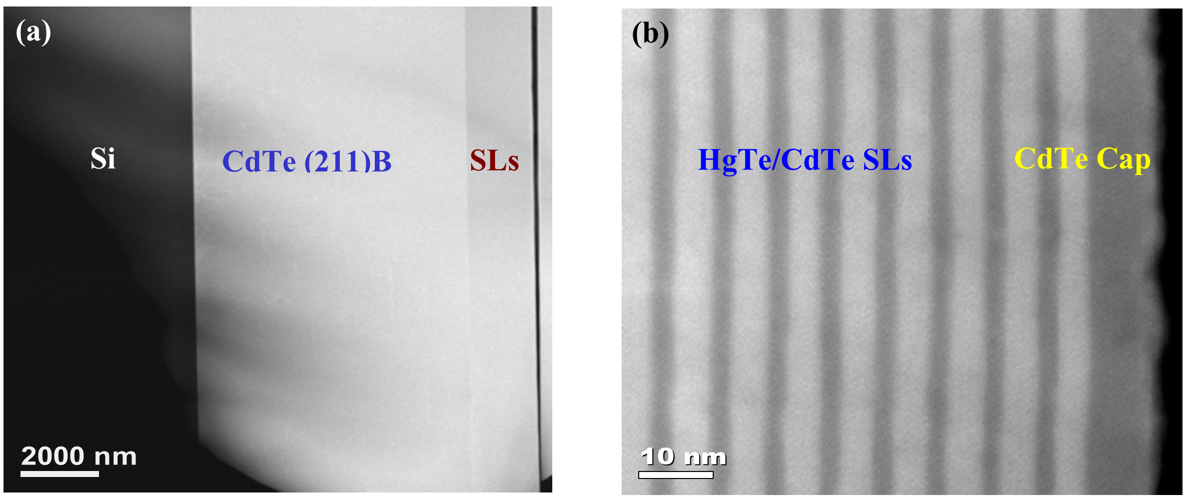

Fig. 1. (a) a cross-sectional STEM Z-contrast image of HgTe/CdTe SLs on a CdTe buffer layer and a Si substrate. (b) a high magnification Z-contrast image of HgTe/CdTe SLs near surface, which shows the individual SL layers are well-defined.

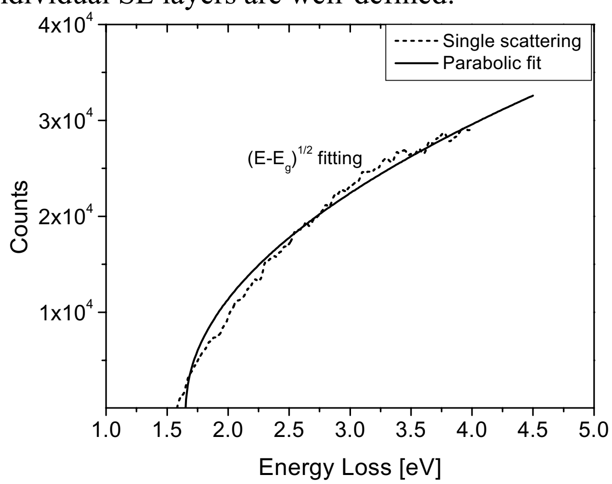

Fig. 2. Band gap region of the single scattering contribution of a CdTe layer revealing the band gap of ~1.65eV. The solid line shows the parabolic fitting used in our study.

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