Structural and optical properties of pulsed laser deposited cadmium telluride thin films

H R Dashtoyan¹, K E Avjyan², L A Matevosyan² and S V Smbatyan¹

¹National Polytechnic University of Armenia, Yerevan, Republic of Armenia
²Institute of Radiophysics & Electronics, NAS of RA, Ashtarak, Republic of Armenia

Abstract. Cadmium telluride thin (< 1 μ) films were grown by pulsed laser deposition method on glass substrates from room temperature up to 300°C. The structural and optical properties were analyzed as a function of substrate temperature and laser radiation intensity.

1. Introduction
Thin films of A²B VI semiconductors, in particular of cadmium telluride (CdTe), have wide application in electronics, integrated optics, optoelectronics, currently being used in many devices, such as field-effect transistors, photodiodes and photovoltaic solar energy converters. One of the most promising application of single and zinc doped crystals of CdTe is their use as a not requiring of additional cooling x-ray and radioactive radiation detectors. This paper presents the results of structural and optical properties of pulsed laser deposited CdTe thin films, obtained under high super-saturation conditions of growth.

Nowadays, PLD being the part of laser technologies and a kind of flexible, universal vacuum deposition, recognized as a simple and versatile method for deposition of thin films and structures based on them [1-3]. This method based on the using of physical phenomena occurring under the influence of laser radiation on solid targets, which reduced to ablation of a substance from the irradiation zone. The method holds of unique characteristics: possibility of evaporation practically all the materials including as well high-melting; short times of deposition (~10⁻⁶ sec.), which is equivalent to improve the “effective vacuum” on a several orders. Practically all materials needed for functional electronics are obtained by this technology. PLD is indispensable for synthesis of a number of complex composite materials with extraordinary properties.

2. Instruments and Experimental Techniques
CdTe films were obtained by the vacuum pulsed laser deposition (PLD) method from crystalline CdTe target on glass substrates from room temperature up to 300°C. The PLD unit consists of a Q-switched YAG: Nd³⁺ laser (1.064 μm wavelength, 30 ns pulse duration, laser energy ~ 0.35 J per pulse) and a vacuum chamber with residual gas pressure 2x10⁻⁵ mm Hg (figure 1). Laser intensity on the CdTe target was varied from 10⁸ W/cm² up to 10⁹ W/cm². The thickness of deposited layer from a single laser pulse was determined by dividing measured by optical interference method of a thick layer on a number of laser pulses (2.5 nm per pulse for 2x10⁸ W/cm² and 4.2 nm for 6x10⁸ W/cm² laser radiation intensities).
Figure 1. PLD system.
1. Quartz lens, 2. Filter, 3. Beam splitter, 4. Calorimeter, 5. Quartz window, 6. Vacuum chamber, 7. Substrate, 8. Substrate holder and heater, 9. Target, 10. Target holder, 11. Motor

The crystal structure of films was investigated by reflection high-energy electron diffraction method (accelerating voltage 75 kV). Independent measurements transmittance ($T$) and reflectance ($R$) of films were made at room temperature by means of spectrometer Filmetrics F20 (spectral range 400-1000 nm) at the normal incidence of light. Absorption coefficient ($\alpha$) was calculated from measured data $R$ and $T$ by using of well known approximate relation in the interference free region:

$$T = (1-R)^2 e^{-\alpha d}/(1-R^2 e^{-2\alpha d}),$$

where $d$ is the film thickness [4]. In order to establish the nature of optical transitions, $\alpha$ was approximated with the empirical Urbach law $\alpha = \alpha_0 \exp(h\omega/E_u)$ ($\alpha_0$ and $E_u$ are the Urbach parameters) and power law $\alpha h\omega = B(h\omega - E_g)^m$, which under certain assumptions describes interband transitions.

3. Results
Beforehand we say that an explicit dependence of the physical properties of obtained films on their thickness is not observed. Electron diffraction studies showed that deposited at room temperature films has amorphous structure regardless laser intensity. CdTe films exhibit polycrystalline structure at 280°C and low (2x10^8 W/cm^2) laser intensities (figure 2).

Figure 2. Electron diffraction pattern from CdTe film.
Figure 3. Absorption of films (a), Ln (ad) plot (b).

Figure 4. Absorption coefficient by power law of 2 (a) and power law of $\frac{1}{2}$ (b).

Figure 3 (a) shows absorption ($A = 1 - R - T$) of films (thickness – 800 nm) deposited at room (1) and 280°C (low laser intensities). It can be seen that a significant absorption observes in films at photon wavelengths less than 850 nm, which is due to the existence of optical absorption edge corresponding to fundamental absorption edge in the CdTe single crystal. Figure 3 (b) shows a plot of Ln (ad) for the amorphous (1) and polycrystalline (2) CdTe film. We can see that these dependencies linearized in the energy range 1.3-1.5 eV for the amorphous film (calculated Urbach “tail” is $E_u = 0.2$ eV. The appearance of the “tails” Urbach in the gap points to an existing structural disorder [5].

Approximation of the absorption coefficient by power law (Fig. 4 (a)) gives the following results:

1. There are optical transitions (1.53 eV for a polycrystalline film and 1.6 eV for the amorphous film, Figure 4 (a)) with a minimum of photon energy (direct allowed transition, $m = 1/2$) as well as in a single crystal CdTe with the sphalerite structure (transition $\Gamma 8v \rightarrow \Gamma 6c$ at the high $\Gamma$ point of Brillouin zone). Direct and allowed optical transition at 1.75 eV is associated with the spin-orbit splitting of the valence band.

2. There is also indirect-allowed optical transition (m = 2) in amorphous film at 1.3 eV (Figure 4 (b)), which is associated with the structural disorder.

4. Conclusion
CdTe thin films were grown on glass substrates by PLD method. The structural and optical properties were investigated as a function of substrate temperature and laser radiation intensity. Electron diffraction studies showed that deposited at room temperature films has amorphous structure regardless laser intensity. Polycrystalline structure is exhibit at low laser intensities and high substrate temperatures. Both amorphous and polycrystalline films have high absorption coefficient above the fundamental absorption edge (1.53 eV for a polycrystalline film and 1.6 eV for amorphous film).
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