The Dark Current-Voltage and Capacitance-Voltage Characteristics of Near-Infrared Sensitive (p)InSb/(n)CdTe Heterostructure

A.V. Margaryan

Institute of Radiophysics and Electronics, Alikhanyan brs. 1, 0203, Ashtarak, Armenia

E-mail: artsrunmargaryan@gmail.com

Abstract. Results of studies of dark current-voltage and capacitance-voltage characteristics of near-infrared sensitive (p)InSb/(n)CdTe heterostructure are presented. It is shown that the junction fabricated by the pulsed laser deposition (PLD) technology has a low number of states at the interface, which leads to the electrical properties explained by physical characteristics of heterostructure pairs.

1. Introduction

Indium antimonide (InSb) based heterostructures (HS) have an attracted attention due to the creation of photodetectors covering the absorption bands of majority gases in the atmosphere and including topical for military applications the main atmospheric "windows" in the near-infrared wavelengths. HS photodiodes have some advantages compared to a homo-junction primarily due to the presence of a "window" effect, which reduces the losses related with the surface recombination of carriers and the high resistance of layer, etc. An essential role is played by the coincidence of crystal structures and lattice constants in choosing of semiconductor HS pairs for providing these advantages. HS could be perfect between the InSb and cadmium telluride (CdTe). The two materials are closely lattice matched (< 0.05 %) and their thermal expansion coefficients are also very similar; therefore InSb is an ideal substrate for the CdTe epitaxial growth. In spite of this, the growth of crystalline CdTe on InSb leads to the formation of incoherent interfaces, which has hindered device fabrication. The compound formed at the interface has been identified as indium telluride (In_2Te_3) [1] or as a stressed InTe phase [2]. Only in [3] was demonstrated the using of pulsed laser deposited (p)InSb/(n)CdTe HS as an infrared-sensitive photodetector (operating temperature is 78 K) with sensitivity close to the limiting value for the photon detectors.

The MOCVD and MBE technologies also were used for fabrication of above mentioned heterostructure [4-7].

This paper presents full and accurate investigations of current-voltage (I-U) and capacitance-voltage (C-U) characteristics of (p)InSb/(n)CdTe HS fabricated by pulsed laser deposition technique.

2. Experimental

The (p)InSb/(n)CdTe HS has been fabricated by simple pulsed laser deposition of CdTe layers (Fig.1) on p-type factory industrial InSb substrate ($N_a=4.17\times10^{14}$cm^{-3}, thickness 400 μm) at 200-225°C. The PLD unit consists of a Q-switched Nd^{3+} : YAG laser (1.064 μm wavelength, 30 ns pulse duration, laser energy – 0.35 J per pulse, laser intensity on the CdTe target ~ 2×10^8 W/cm^2) and a vacuum chamber with residual gas pressure of 4×10^{-5} mm Hg. The thickness of deposited layer was determined from reflectance spectra of fabricated (p)InSb/(n)CdTe structure by using Filmetrics F20 thin-film measuring system. The thickness of layer deposited from a single laser pulse was estimated by dividing layer thickness by a number of laser pulses, which was 3.5 nm per laser pulse. To produce position sensitive photo-detector, an indium contacts were evaporated onto two sides of structure: common backside electrode from (p)InSb side and point contacts with diameter of 0.4mm from (n)CdTe side.
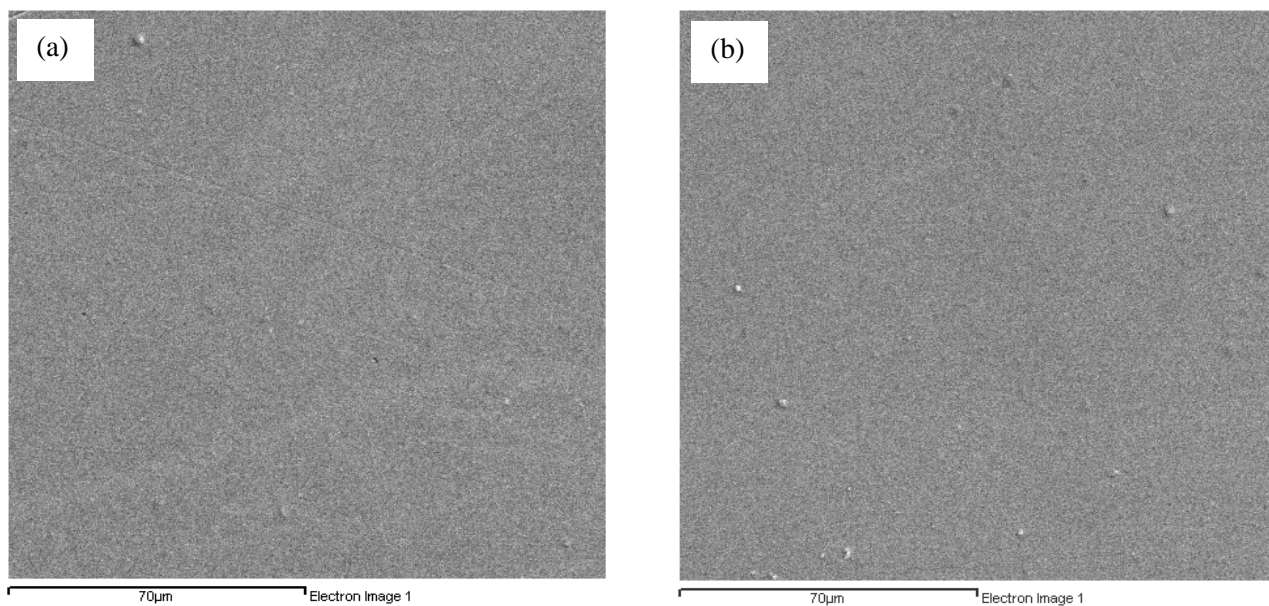

Fig. 1 Morphology of CdTe layers obtained by scanning electron microscope from two different samples

3. Results

Dark I-U and C-U characteristics of fabricated (p)InSb/(n)CdTe HS ((p)InSb substrate thickness - 500 µm, $N_a(InSb) = 4.17 \times 10^{14}$ cm^{-3}, CdTe film thickness – 0.75 um, surface of junction – 5×10^{-3} cm^2) were investigated at liquid nitrogen temperature (78 K) by means of sub-femtoamp source meter KEITHLEY-6430 and digital RLC Meter E7-25.

a) I-U characteristics

Fig. 2 shows dark I-U curve of (p)InSb/(n)CdTe junction. We have a rectifying junction with rectifying coefficient k (ratio of forward current to reverse) of 1.1×10^2 at 0.7 V bias voltage. Higher than 0.5 V direct current (+ on (p)InSb) is characterized by linear dependence of $I = (U - U^I_{cut\ off})/R_d$, with current cut-off voltage $U^I_{cut\ off} = 0.46$ V and residual differential resistance $R_d = 14.4$ Ohm. The numerical value of $U^I_{cut\ off}$ equals to the total contact potential in the n- and p-areas (Anderson model)[8]. I-U characteristic of junction at direct biases 0.01 V < U < 0.4 V satisfactory fits with the expression $I = AV^2$ (A = 0.055), which indicates the predominance of the space-charge-limited current. At low biases (≈ 0.01 V), the value of current is 10^{-5} A in both directions.
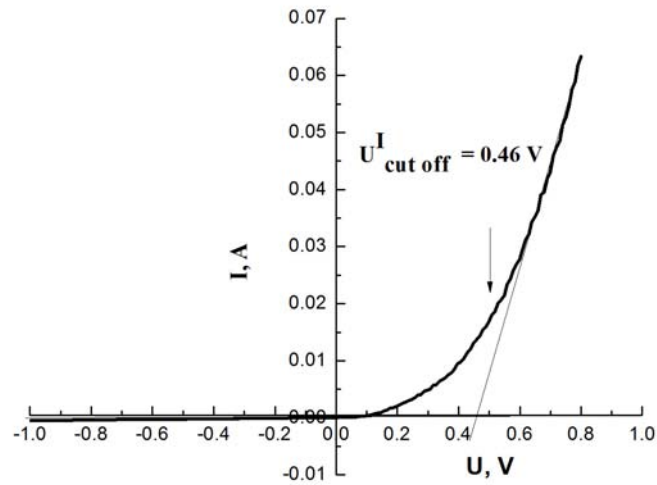

Fig.2. Dark I-U curve of (p)InSb/(n)CdTe junction.

b) C-U characteristics.

Fig. 3 shows $1/C^2$ dependence on the voltage measured at 1 MHz for (p)InSb/(n)CdTe junction (+ on CdTe). The linearization of dependence C^{-2}-U (capasitance cut-off $U^C_{cut\,off}$ = 0.4 V) indicates the sharpness of impurity distribution in depletion region of CdTe. The depletion layer width (W = 0.62 um) was calculated based on equation W = $\varepsilon_{CdTe}\varepsilon_0 S/C(0)$, where ε_{CdTe} = 9.6, ε_0 = 8.85×10^{-14} F/cm, C(0) = 68.7 pF. The maximum value of the electric field in the space charge region is E_m = 1.29×10^4 V/cm (E_m = 2$U^C_{cut\,off}$/W). The diffusion potential (associated with a contact potential of heterojunction forming materials) obtained from the C^{-2}-U data equals to $V_{di} \approx$ 0.41 V ($V_{di} = U^C_{cut\,off}$ + kT/e).
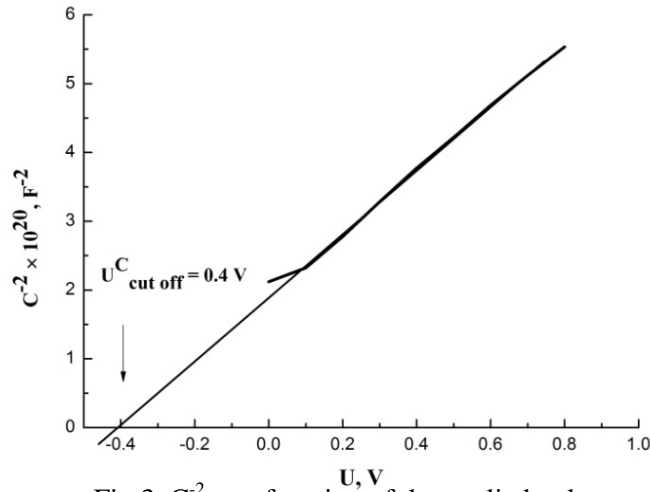
Fig.3. C^{-2} as a function of the applied voltage.

From the slope of the curve in Fig. 3, the carrier concentration in CdTe film (N_d(CdTe) = 1.28×10^{15} cm^{-3}) was calculated based on equation $\Delta(1/C^2) = 2\Delta V/(eN_d\varepsilon_{CdTe}\varepsilon_0)$. The table 1 shows the main parameters of (p)InSb/(n)CdTe structure.

Table 1. Main parameters of (p)InSb/(n)CdTe structure.

Junction	V_{di}, eV	$U^I_{cut\,off}$, V	E_m, V/cm	R_d, Ohm	N_d(CdTe), cm^{-3}	k	C(0), pF
(p)InSb/(n)CdTe	0.41	0.46	5.16×10^4	14.4	1.28×10^{15}	1.1×10^2 at 0.7 V	68.7

4

Obtained value of V_{di} is less than the total contact potential $U^I_{cut\ off}$ determined from the linear part of I-U characteristics (see Fig. 2). This fact is well explained in the framework of the model proposed by Donnelly and Milnes [8], taking into account the presence of an electric charges localized on the surface states of the heterojunction interface: $V_{di} = U^I_{cut\ off} - Q^2_{ss}/2e(\varepsilon_{InSb}N_a + \varepsilon_{CdTe}N_d)$, where $Q_{ss} = eN_{ss}$ is a density of electrical charge stored at the heterojunction interface. Calculated from that equation the number of surface states equals to $N_{ss} \approx 6 \times 10^{12}$ cm^{-2}. This value is in satisfactory agreement with the theoretical $N_{ss} = 6.2 \times 10^{11}$ cm^{-2} value ($N_{ss} \approx 1/a^2_{InSb} - 1/a^2_{CdTe}$, where a_{InSb} and a_{CdTe} are lattice parameters).

5. Conclusion

Thus, for the first time were carried out complete studies of the electrical properties of pulsed laser deposited near-infrared sensitive (p)InSb/(n)CdTe heterostructure. Based on electrical measurements it is shown that PLD technique is very successful technology for fabrication of (p)InSb/(n)CdTe heterostructure with low number of states at the p-n junction interface.

References

1. Zahn et al. Appl. Surf. Sci. 41/42, 497 (1989).
2. Van Welzenis et al. Appl. Phys. A52, 19 (1991).
3. L. A. Matevosyan, K. E. Avjyan, S. G. Petrosyan, A. V. Margaryan. "Photoelectrical properties of (p)InSb–(n)CdTe heterojunction". USPEKHI PRIKLADNOI FIZIKI (ADVANCES IN APPLIED PHYSICS) Vol. 2, No. 4, p. 403 (2014).
4. R.F.C. Farrow, G.R. Jones, G.H. Williams & I.M. Young, Appl. Phys. Lett. 39, 954 (1981).
5. K.J. Mackey, P.M.G. Allen, W.G. HerredenHarker, R.H. Williams, C.R. Whitehouse & G.M. Williams, Appl. Phys. Lett. 49, 354 (1986).
6. T.W. Kim, Y.H. Chang, Y.D. Zheng, A.A. Reeder, B.D. McCombe, R.F.C. Farrow, T. Temofonte, F.A. Shirland & A. Noreika, J. Vac. Sci. Technol. B5, 980 (1987).
7. G.M. Williams, C.R. Whitehouse, N.G. Chew, G.W. Blackmore & A.G. Cullis, J. Vac. Sci. Technol. B3, 704 (1985).
8. J.P. Donnelly, A.G. Milnes. IEEE Trans. Electron. Dev., ED-14, 63 (1967).