Properties of Infrared Detectors Made of $Pb_{1-x}Mn_xTe/CdTe$ Multilayer Composite

S. Chusnutdinow[1,2], A. Kazakov[2], M. Szot[1,2], S. Schreyeck[3], R. Jakieła[1], K. Brunner[3] and G. Karczewski[1,3]

[1]Institute of Physics, Polish Academy of Sciences, aleja. Lotników 32/46, PL-02-668 Warsaw, Poland
[2]International Research Center MagTop, aleja Lotników 32/46, PL-02-668 Warsaw, Poland
[3]Physikalisches Institute, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

Introduction:

Infrared detectors are widely used for various purposes, such as chemical gas analysis, gas leak detection, IR imaging, remote temperature measurements, etc. In particular, there is continued interest in applications and consequently in the development of IR detectors operating at room temperature. We have shown experimentally that photoresistors made of the PbTe/CdTe multilayer composite are highly sensitive to infrared light, and their detectability at room temperatures is comparable to that of commercially available infrared detectors [1]. The high performance of PbTe/CdTe detectors is due to three factors. The first factor is a significant reduction in the concentration of free carriers in conductive PbTe layers due to their capture by broken bonds located at PbTe/CdTe interfaces. The atomic bonds at the interfaces are broken because of the different crystal structures of PbTe and CdTe, the rock salt and zinc blende, respectively. The second factor is a high mobility of carriers present in the PbTe layers. Despite the huge number of defects at the interfaces, the high mobility is preserved due to the high dielectric constant of PbTe, which effectively screens the scattering centers at the interfaces.

Structures composed of a combination of PbTe and CdTe have been the subject of study for quite some time and exhibit interesting and distinctive properties. In particular, the components are almost completely immiscible due to their different crystal structures, although they crystallize in cubic structures and have nearly identical lattice constants (6.46 and 6.48 Å, respectively). Specifically, PbTe has a rock salt structure, while CdTe has a zincblende structure. The PbTe/CdTe material system exhibits a crucial feature—a significant difference in energy gaps (PbTe = 0.32 eV; CdTe = 1.59 eV) and type I band ordering.

The main objective of the present work is to check how manganese atoms introduced into PbTe layers affect the performance of IR photoresistors made of $Pb_{1-x}Mn_xTe/CdTe$ multilayer composite. It is known, that Mn effectively increases the energy gap of $Pb_{1-x}Mn_xTe$ [2], which leads to the increase of carrier effective masses and thus of the density of states. As a result, the concentration of carriers is expected to decrease with the increasing manganese content, x, which in turn should made the of $Pb_{1-x}Mn_xTe/CdTe$ photoresistors more sensitive to optical excitation. Properties of $Pb_{1-x}Mn_xTe/CdTe$ multilayer composite grown by molecular beam epitaxy on GaAs substrates have been studied [3].

[1] S. Chusnutdinow, S. Schreyeck, S. Kret, A. Kazakov, G. Karczewski, *Applied Physics Letters*, 117, 072102 (2020).
[2] V. Osinniy, A. Jedrzejczak, W. Domuchowski, K. Dybko, B. Witkowska, T. Story, *Acta Physica Polonica A,* 108, 803 (2005).
[3] Chusnutdinow S, Kazakov A, Jakieła R, Szot M, Schreyeck S, Brunner K, Karczewski G. *Materials*. 2023; 16(12):4211.

Growth and characterization methods

- MBE
- Substrates – (001)-oriented CdTe/GaAs SI
- Sources - effusion cells with solid sources: Cd, Pb, Te, Zn, Mn
- Temperature of growth : 240^0C
- HRXRD, SEM, SIMS
- Current − Voltage characteristics
- Noise power density
- Photoluminescence,
- Spectral responsivity
- Hall effect measurement

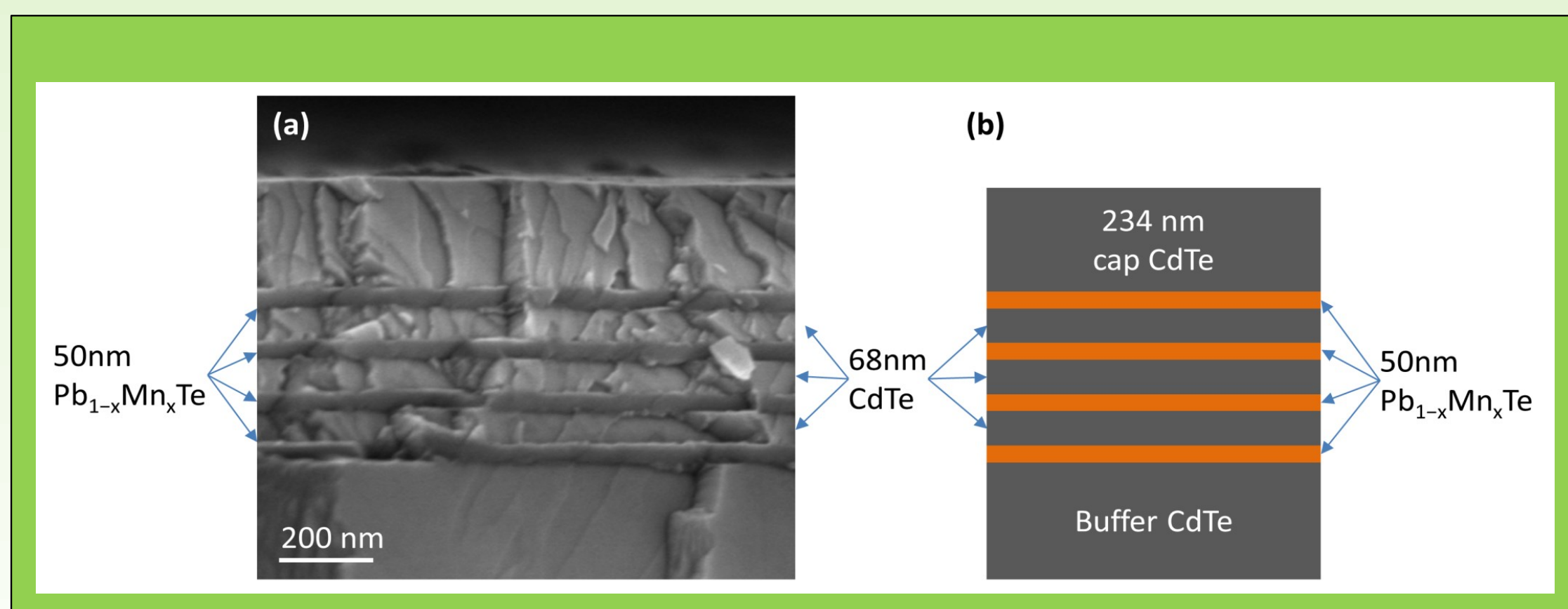

Figure1 . (a) SEM image of cleaved surface of $Pb_{1-x}Mn_xTe/CdTe$ multilayers and (b) the schematic of the grown structure.

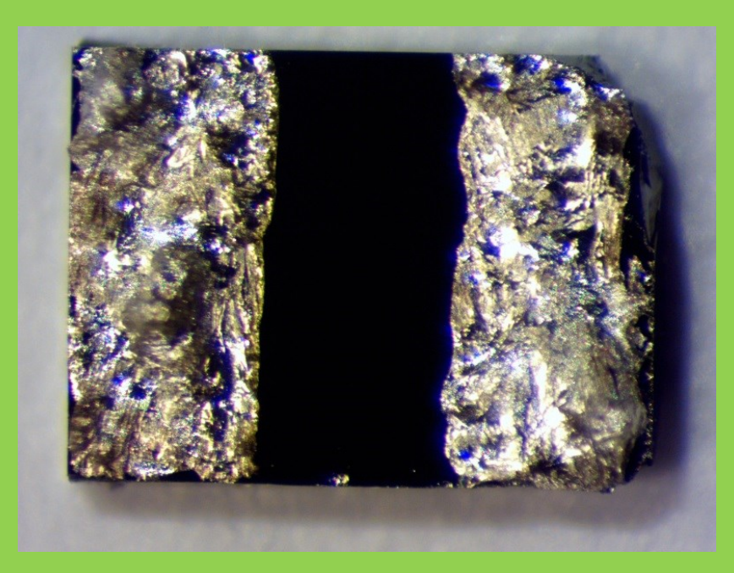

Figure 2. Picture of the fabricated typical photoresistor

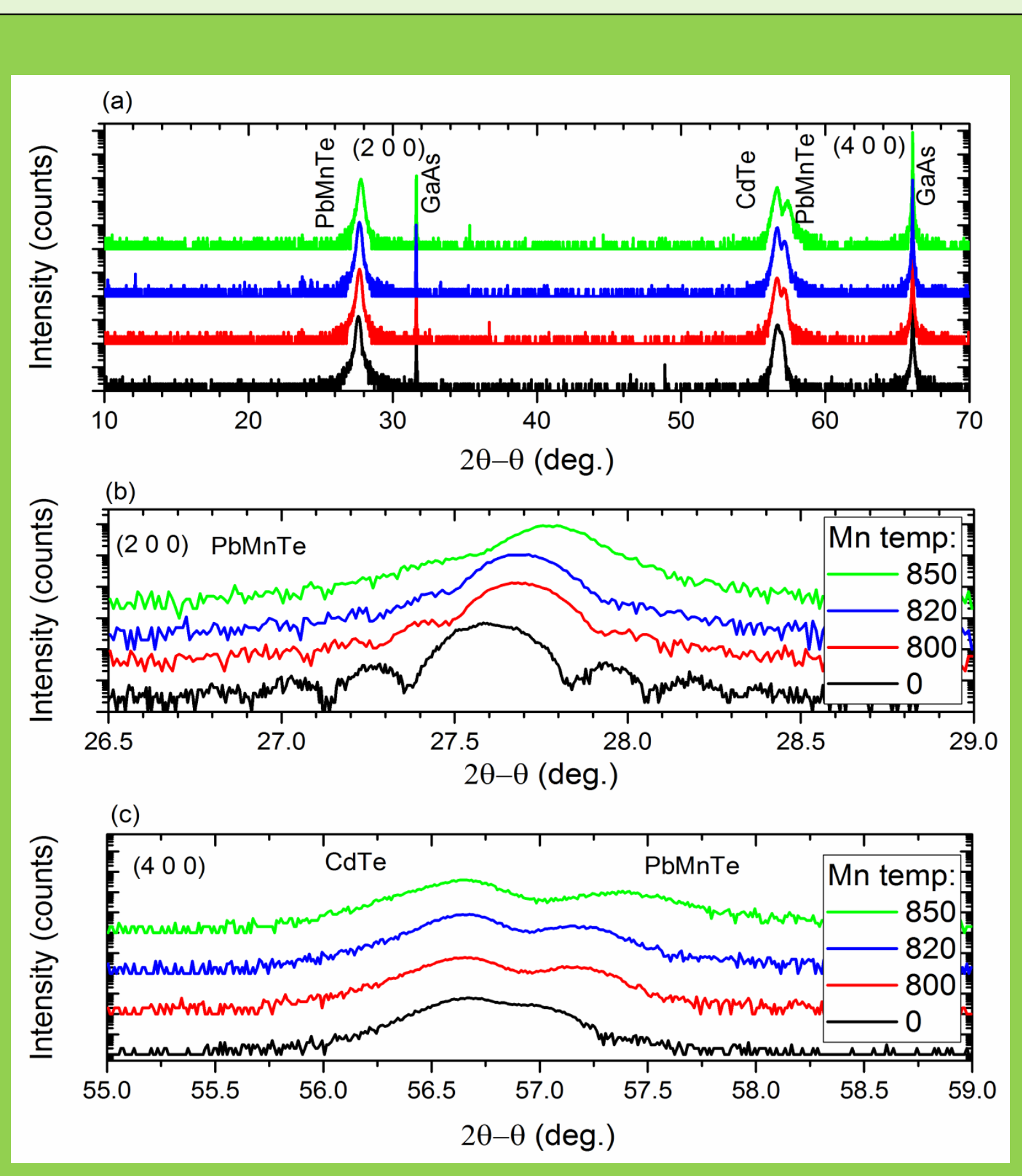

Figure 3. (a) The (2θ−θ) wide-angle X-ray diffraction scans of $Pb_{1-x}Mn_xTe/CdTe$ multilayers and (b,c) the high-resolution diffraction scans.

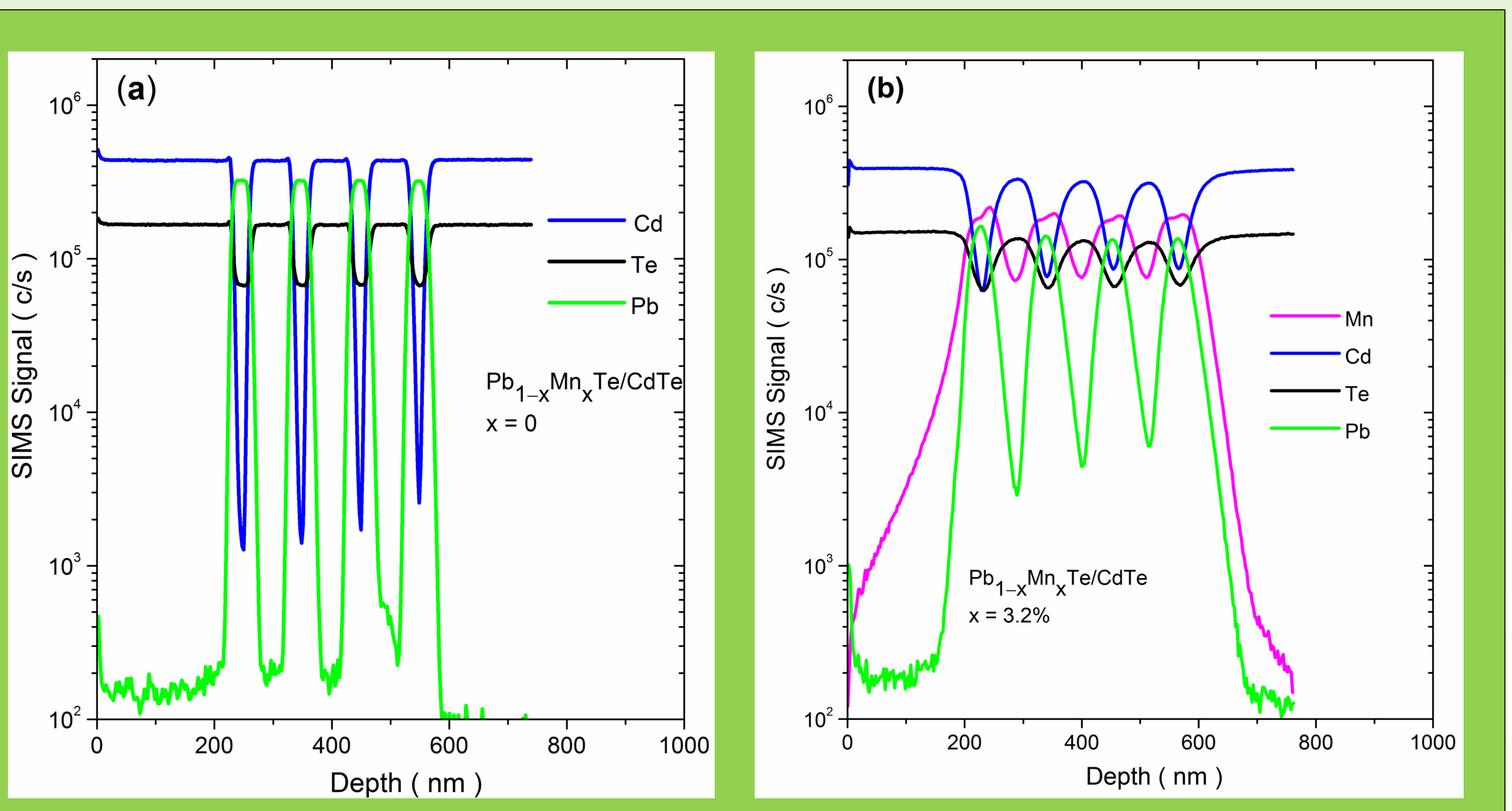

Figure 4. SIMS depth profile of Mn, Cd, Te, and Pb in the $Pb_{1-x}Mn_xTe/CdTe$ multilayers photoresistors, (a) x = 0 and (b) x = 3.2%.

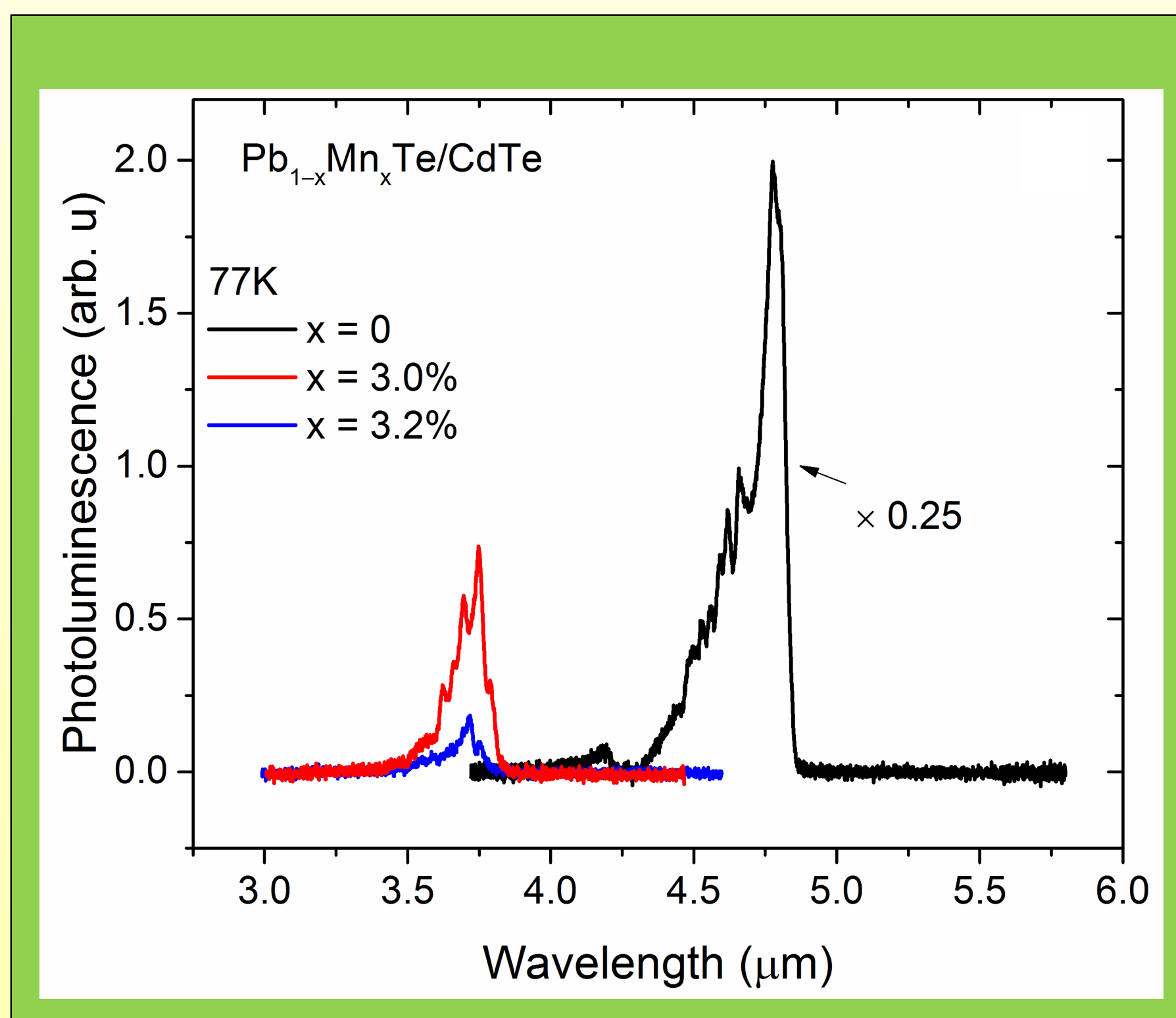

Figure 4. Photoluminescence spectra of the $Pb_{1-x}Mn_xTe/CdTe$ structures at 77 K.

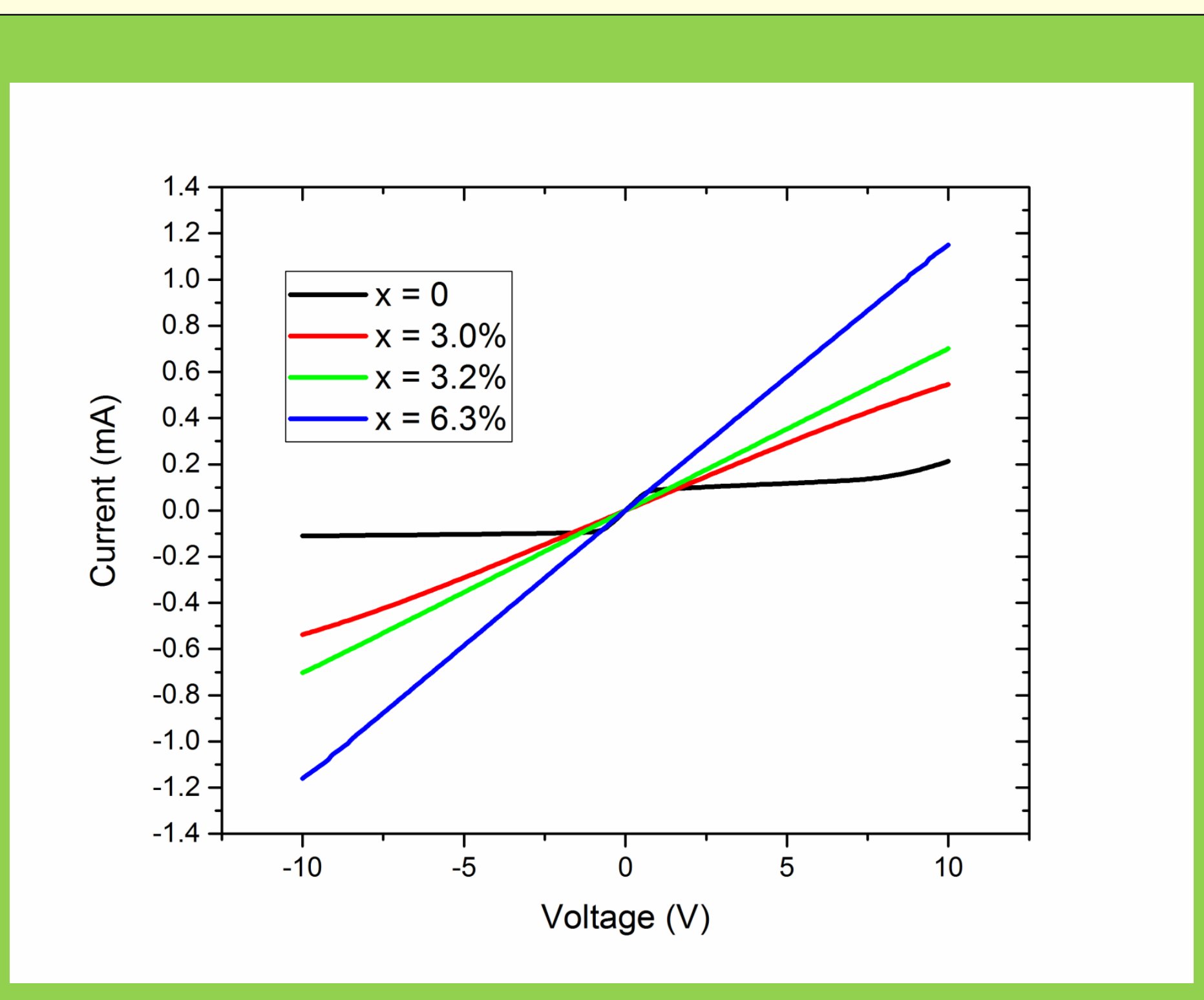

Figure 5. Current-voltage characteristics of fabricated photoresistors

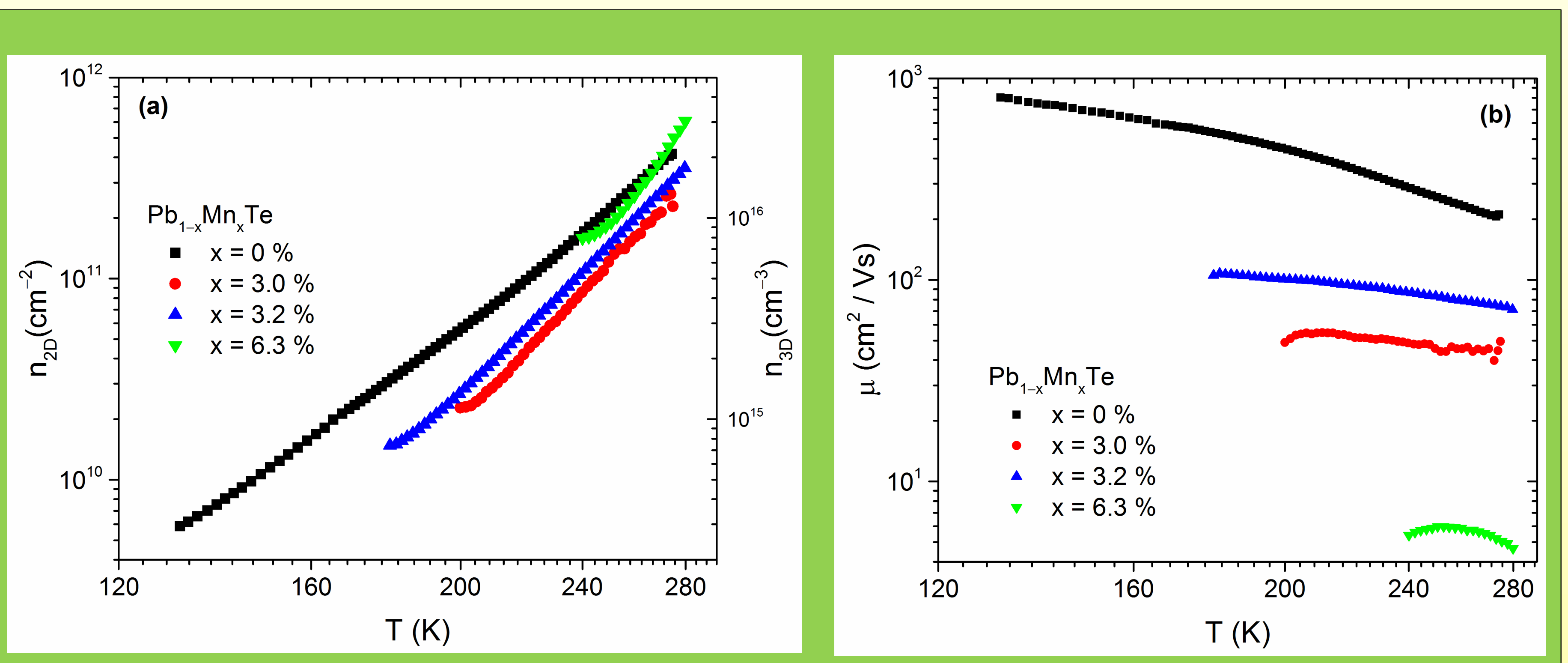

Figure 6. (a) Electron carrier concentration and (b) electron mobility of the $Pb_{1-x}Mn_xTe/CdTe$ multilayer structure plotted in logarithmic scale.

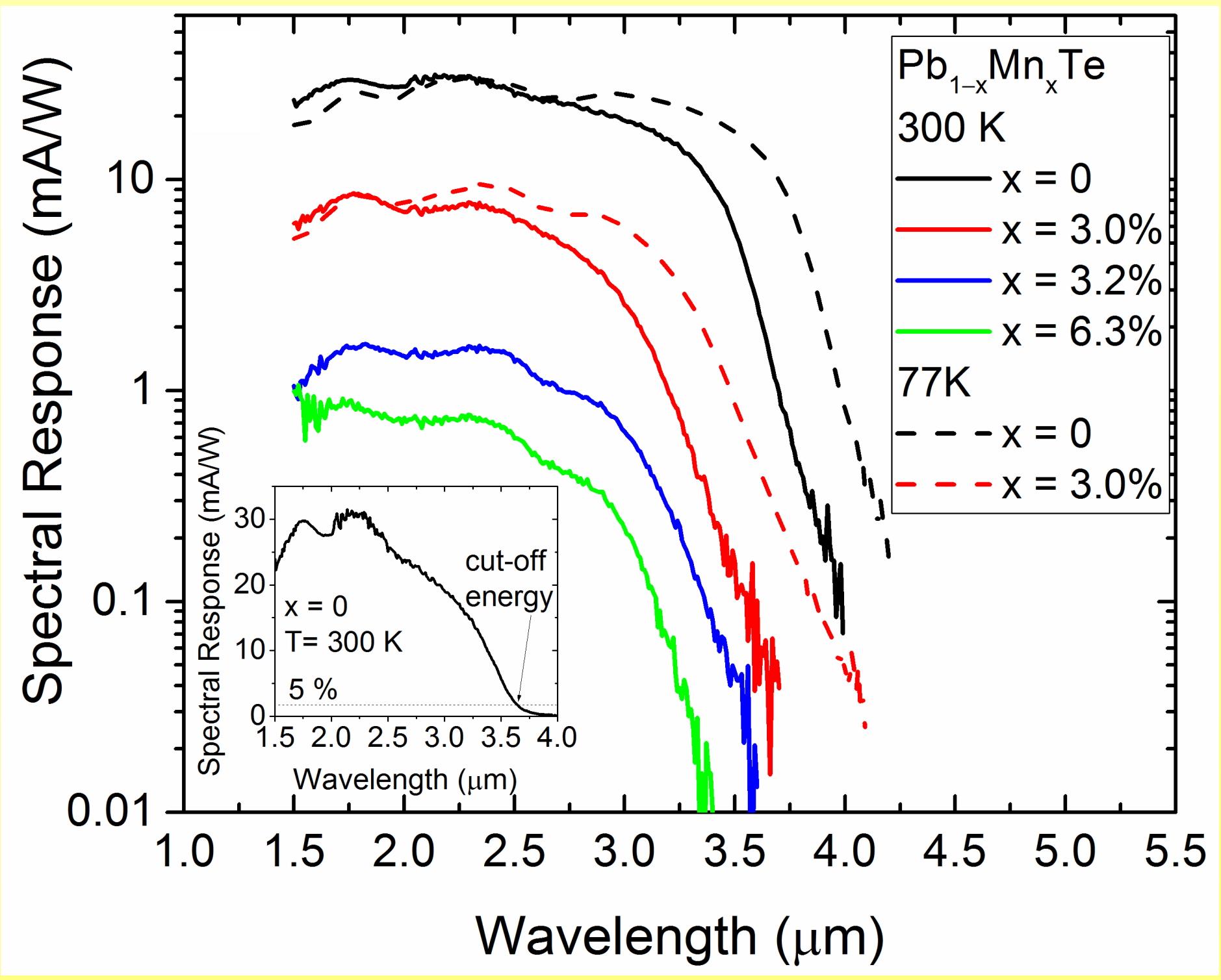

Figure 7. Spectral response of the $Pb_{1-x}Mn_xTe/CdTe$ photoresistors at 77 and 300 K. In the inset, the spectral response of the PbTe/CdTe multilayer photoresistor on a linear scale.

Table 1. Measured and calculated parameters of photodetector.

Mn Content	R_i	S_n	R_0	A	D^*
%	mA/W	$\frac{V}{\sqrt{Hz}}$	kOhm	cm²	$cm \times \frac{\sqrt{Hz}}{W}$
0	25.0	1.1×10^{-8}	7.5	0.021	3.5×10^8
3.0	6.3	1.6×10^{-8}	17.0	0.025	1.7×10^8
3.2	1.4	1.5×10^{-8}	14.2	0.028	3.6×10^7
6.3	0.60	2.1×10^{-8}	8.6	0.019	8.0×10^6

$$R_i = \frac{I_{ph}}{P} \qquad D^* = \frac{R_i R\sqrt{A}}{S_n}$$

I_{ph} − photocurrent, P − the incident optical power, R_i − the spectral responsivity, S_n is the noise voltage spectral density, R_0 is the resistance of the structure determined from the I–V characteristic at V = 0V, A is the photosensitive surface area, D^* − the specific detectivity of the photoresistor.

Conclusions

- In summary, we studied the effects of Mn alloying on the properties of a $Pb_{1-x}Mn_xTe/CdTe$ multilayer composite grown by molecular beam epitaxy on GaAs.
- The study included high-resolution X-ray diffraction morphological characterization by scanning electron microscopy, secondary ion mass spectroscopy, magneto-transport, and optical properties analysis.
- The decrease in PL intensity and total disappearance of structures containing 6.3 at.% Mn confirmed the creation of such non-radiative recombination centers.
- The main focus of the study was on photoresistors made of $Pb_{1-x}Mn_xTe/CdTe$ and their sensing properties in the infrared spectral region. It was shown that the presence of Mn in the conductive layers of $Pb_{1-x}Mn_xTe$ weakened the spectral sensitivity and shifted its cut-off at long wavelengths toward blue.
- The first effect was due to an increase in the energy gap of $Pb_{1-x}Mn_xTe$ with an increase in Mn concentration, and the second effect was due to a pronounced deterioration in the crystal quality of the multilayers owing to the presence of Mn atoms.
- The specific detectivity was calculated.

Acknowledgements

The research in Poland was supported by the National Science Centre (Grant No. 2021/41/B/ST3/03651) and partially by the Foundation for Polish Science through the IRA Programme co-financed by the EU within SG OP (Grant No. MAB/2017/1) and in Germany by the DFG through SFB 1170 "ToCoTronics" (project No. A05).