Wide gap II-VI diodes with PbTe nano inclusions for infrared detection and photovoltaics

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Introduction:

In this paper, we present the experimental characterization of p-n diodes made of wide-band-gap II-VI materials with narrow-band-gap PbTe nano-inclusions located in the depletion region of the diodes. The diode structures (p-ZnTe/PbTe nano-inclusions/n-CdTe) were fabricated by molecular beam epitaxy (MBE) from elemental Cd, Zn, Pb and Te sources on monocrystalline semi-insulating (100) GaAs substrates. The p-type ZnTe layers were doped with nitrogen from a nitrogen plasma source. The n-type CdTe layers were doped with iodine from a ZnI_2 source. The PbTe nano-inclusions have a form of a set of PbTe/CdTe multilayers or a set of PbTe quantum wells in CdTe matrix or a single, thick PbTe layer.

The main focus was on investigating the sensing capabilities of photodiodes in the infrared spectral range, with a particular focusing on the temperature dependence of the diodes' spectral response. The characteristics of the diode were also analyzed. The height of heterojunction barriers and the diode ideality factors were determined. Current-voltage characteristics were measured both in darkness and under infrared illumination. Analysis of the diodes' spectral response curves revealed bands localized in the infrared region, which were attributed to optical absorption by the PbTe nano-inclusions. Electron Beam Induced Current (EBIC) measurements confirmed the formation of junctions in the depletion region. The diffusion length and activation energy of charge carriers were extracted from EBIC scanning profiles. The investigated structures demonstrated significant promise for applications in infrared sensors.

Detectors structures

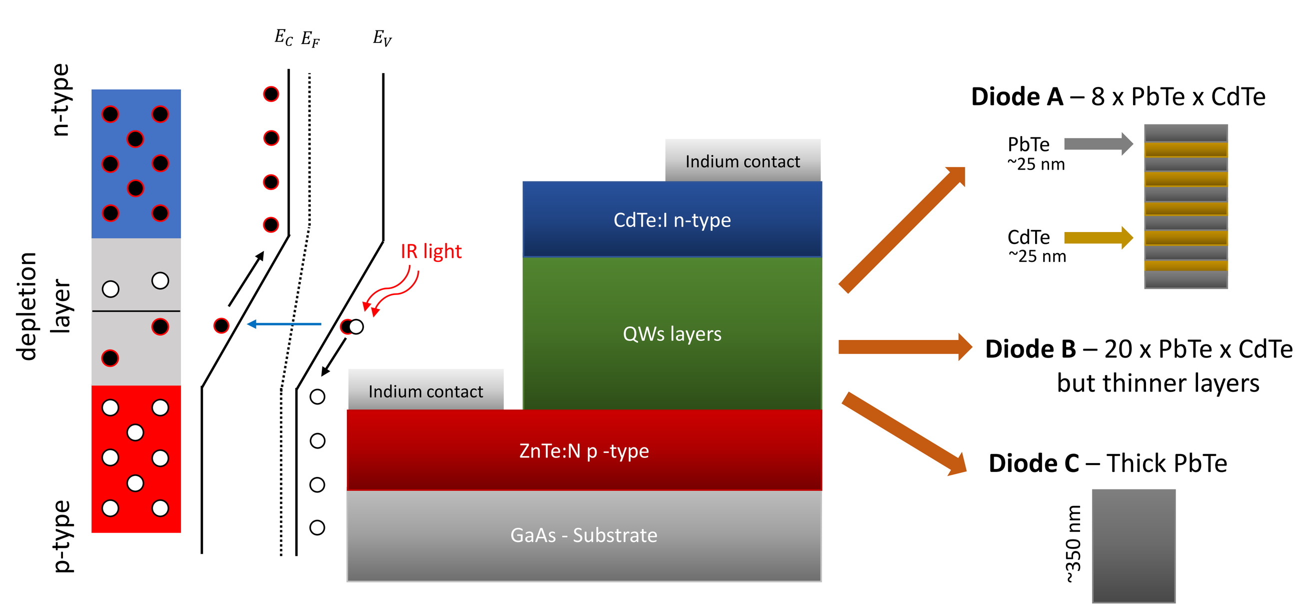


Figure 1. Cross-section structures for three types of measured detectors. Two of them have multiple quantum wells with alternating layers of PbTe and CdTe materials, placed on top of each other. Last type of detector have one thick PbTe layer.

Spectral Response

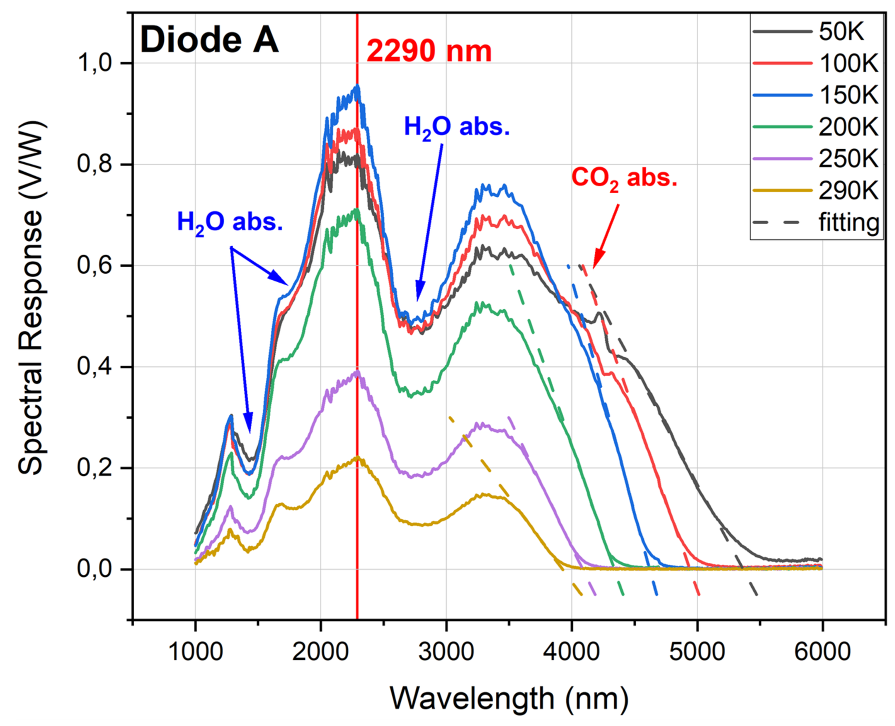


Figure 2. Spectral Response in infrared for diode A at various temperatures[1]. With increasing temperate maximum signal increase up to 150K. With further increase of temperature the sensitivity of the detector decrease, as shown in the inset.
Also increase of the temperature decrees detectability of device in further region of infrared.

Band gap

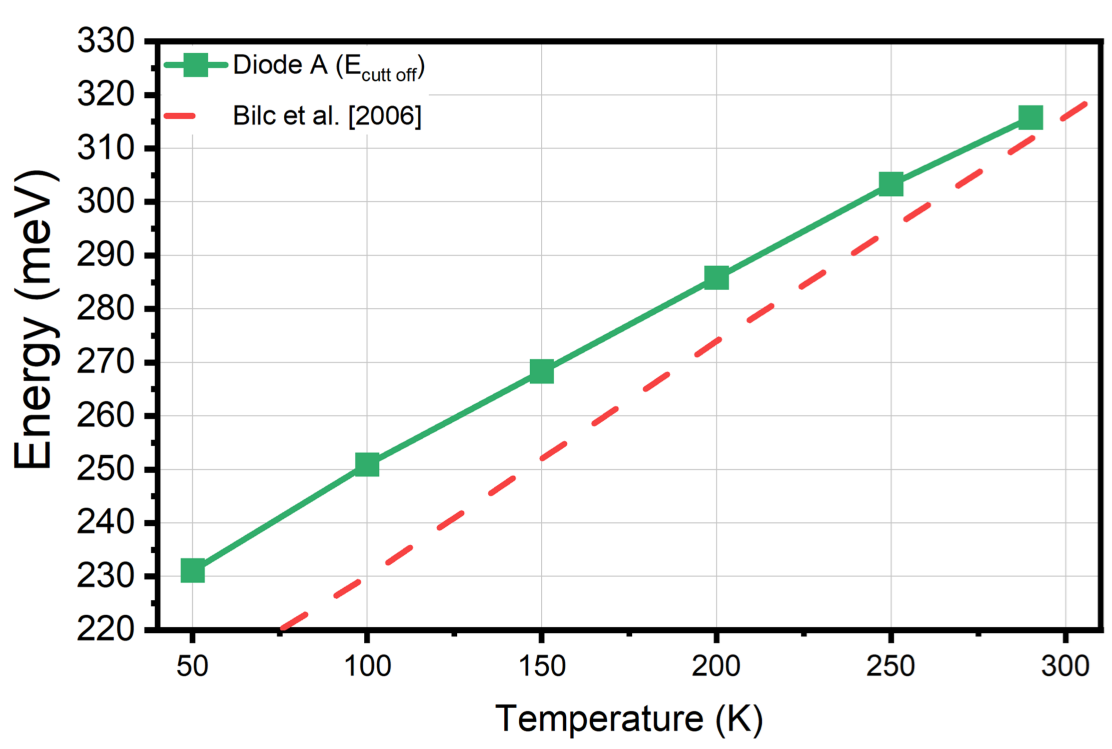


Figure 3. Change in detective energy in detector A at various temperatures[1]. Energy was calculated from the cutoff wavelength (obtained from linear extrapolation of the low-energy edge of the sensitivity spectrum). This is simplified method of obtaining bang gap. Energy from the experiment is shifted upward compared to theoretical data of bulk PbTe[2].

[2] D. I. Bilc, S. D. Mahanti, and M. G. Kanatzidis, Phys. Rev. B 74, 125202(2006)

I-V characteristics

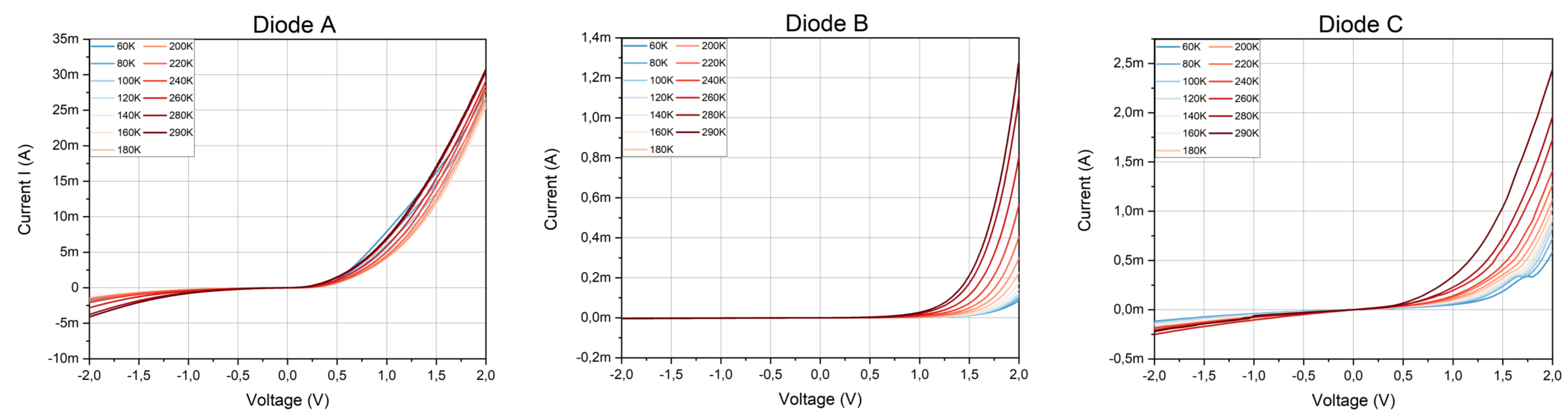


Figure 4. Current – voltage measurements in linear scale of three types of detectors measured at various temperatures. Sample B exhibit the most similar profile to ideal diode characteristic, with high current in forward bias and almost no current in reverse bias. Detector A have worse quality curve profile that sample B, but achieved much higher currents with the same bias.

Build-in voltage, Series resistance and Ideality factor

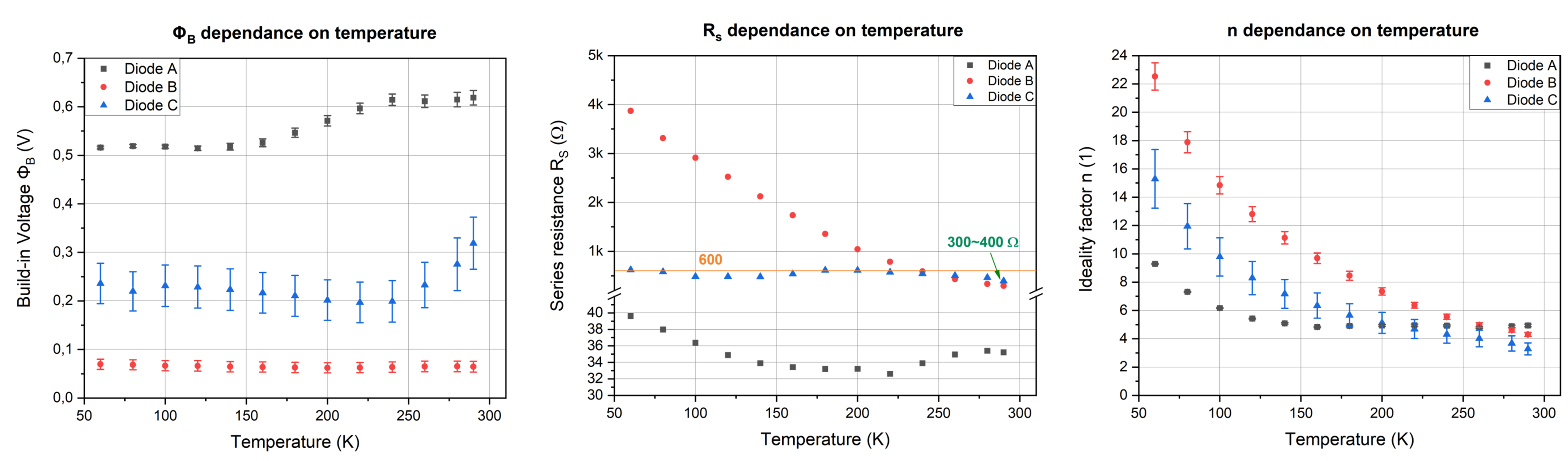
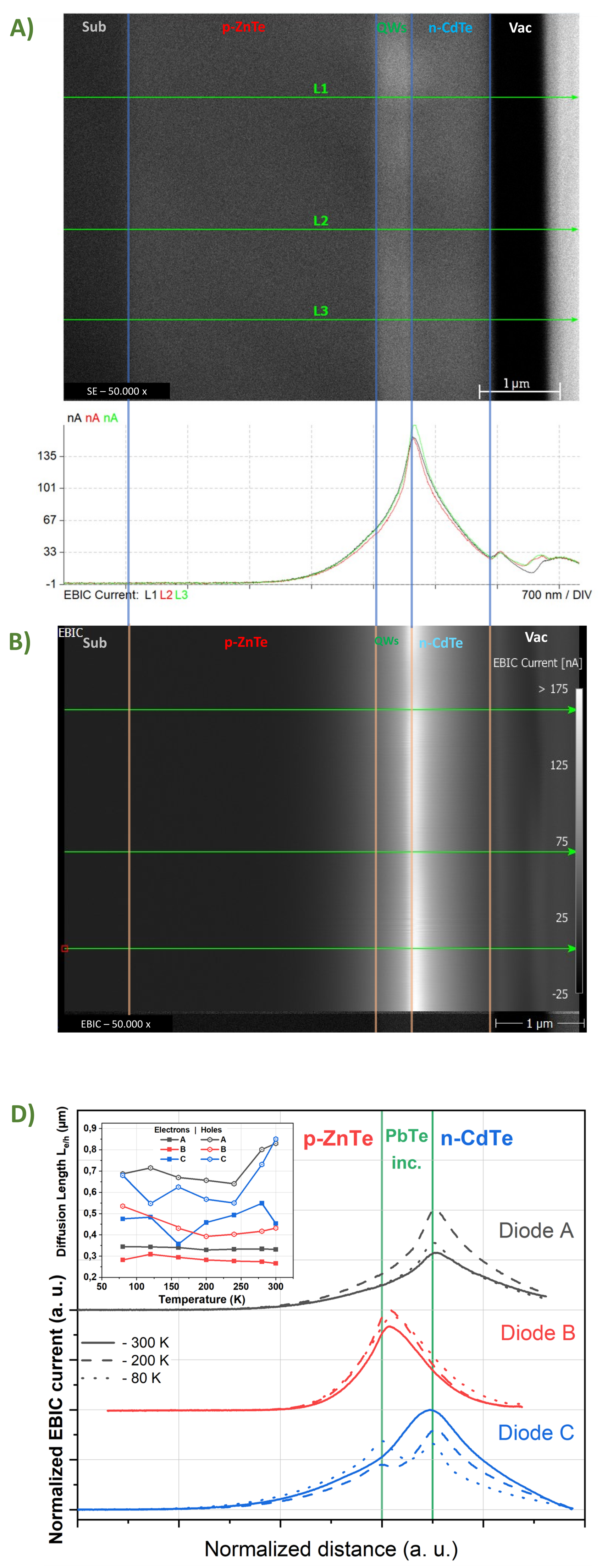


Figure 4. Build-in voltage, series resistance and ideality factors calculated for each diode from I-V measurements. Detector A exhibit lower each values and that indicate that this type of detector have the most favorable structure for IR detector among those three types. Due to high series resistance, ideality factors for those structures are also high and above 2.

EBIC measurement



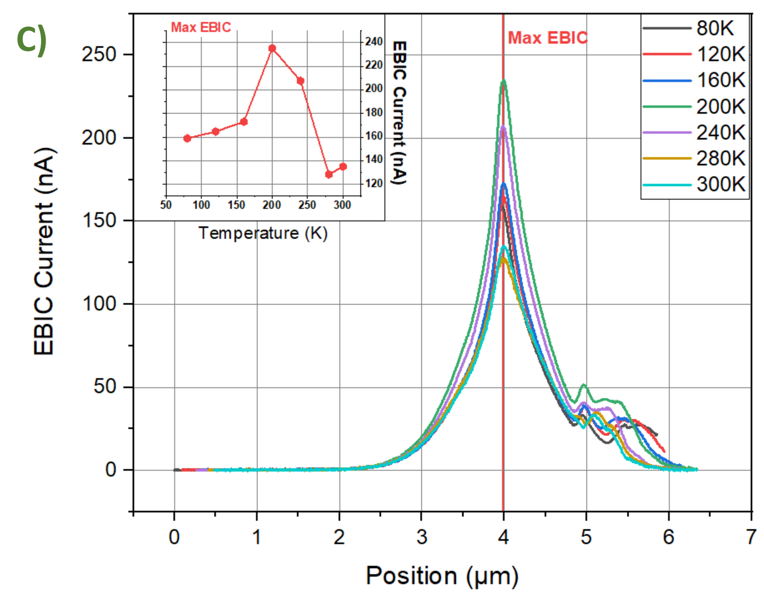


Figure 5. **A)** – Top picture represent SEM image at the cross-section of detector A in 80K with distinguished different structure layers. Bottom graph show measured EBIC current collected at the three green lines (L1,L2,L3) from SEM image. Maximum of the signal show that the depletion region of junction is formed in this detector between QW-s layers and n-type layer.
B) – Surface map of EBIC current collected from the same area as SEM image. Junction go along with interface of between QW-s layers and n-type layer.
C) – Change of EBIC current at the cross-section and it maximum peak at different temperatures for detector A. With increasing temperature increase also current and is maximum around 200K but with higher temperature current drop.
D) – EBIC line scans of obtained for diodes A, B and C at various temperatures with EBIC signals normalized to their maximal values[1]. In inset - diffusion Length dependance from temperature for each detectors for electron and holes (left and right side of slopes of EBIC).

Conclusions

Based on the analysis of the results, following conclusions have been drawn:

- Created diodes can absorb infrared light and work as detectors.
- Temperature dependance measurements show a change in the energy related to the PbTe band gap, which is shifted to higher values due to quantum effects in this structure compared to bulk PbTe theoretical data.
- Detector A achieved the strongest spectral response and exhibit the lowers build-in voltage, series resistance and ideality factor. These values allow us to conclude that a much larger number of layers or a single layer does not have a positive impact on the quality of these parameters. Although detector B have the most similar I-V curve to ideal diode, this does not translate into quality of detection.
- EBIC measurements show formation of junction in different places for each detector. In A maximum EBIC signal is between QW-s layers and n-type layer. In B between QW-s layers and p-type layer. Detector C show formation of 2 junction between QW-s and p-type layer and also between QW-s and n-type layer. This detector show that using only single thick layer of IR sensible material is not the right direction for detector development.
- Due to almost no significant dependance of diffusion length from temperature for each diode, calculated activation energy are around single meV.

Plans for the future

- Improving diode development – better quality would allow to decrease resistivity of metallic contacts that influence all calculated parameters in this work.
- Additional spectral response and C-V measurements to calculate other parameters.
- Reflectance simulations and IR reflectance and transmittance measurements. To better develop future detectors there is a need to check how much IR light are actually absorbed with detector and not reflected or transmitted.

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[1] Wide gap II-VI diodes with PbTe nano inclusions for infrared detection and photovoltaics, J. M. Gluch, M. Szot, S.Chusnutdinow and G. Karczewski - Waiting for the publication in APL

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