

## Conductivity mechanisms of PbTe(In) films with variable microstructure

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### Introduction

Lead telluride is a narrow gap semiconductor with direct energy gap of 190 meV. Due to high dielectric constant of PbTe, indium doping is accompanied by impurity - lattice correlation processes which give rise to a mixed valence behavior of the impurity, the Fermi level (FL) pinning, and the low-temperature ( $T < 25$  K) persistent photoconductivity. In PbTe(In) single crystals, the FL is pinned at 70 meV above the conduction band edge providing free electron concentration  $n = 6 \cdot 10^{18} \text{ cm}^{-3}$  [1]. For polycrystalline films the energy spectrum and charge transport mechanisms depend on the grain boundary and grain surface properties. The relation between the contributions of different structure elements to conductivity may be affected by a structure variation (grain size, degree of oxidation, doping) as well as by external factors (AC frequency, illumination). In this paper, we have studied the grain size and the grain barrier effect on photoelectric and transport properties of PbTe(In) films in the temperature range from 4.2 K up to 300 K, in DC and AC modes, at illumination with a thermal radiation source and under terahertz laser pulses.

### Results and Discussion

PbTe(In) films were deposited on insulating substrates kept at the temperatures -120 C and 250 C by Physical Vapor Deposition using an electron gun. AFM, SEM, Auger spectroscopy and X-ray diffraction were used to study the film microstructure. All films have a column-like structure with nearly equal orientation of the columns perpendicular to the substrate plane. The column diameter was taken as the grain size. Thickness of the films was varied within 0.1 – 1  $\mu\text{m}$ . Increase of the substrate temperature leads to mean grain size growth from 60 up to 300 nm. In the polycrystalline films with the mean grain size of 300 nm, appearance of the (200) preferred orientation of the columns was observed.

Increase of the grain size is also accompanied by the inversion the conductivity type from p- to n- and by the change in the conductivity temperature dependence type from the activation to the metallic one. Analysis of impedance spectroscopy data confirmed that in the nanocrystalline films, the grain barriers give the dominant contribution to conductivity, and the activation energy corresponds to transitions to the mobility edge. The persistent photoconductivity is due to the energy band modulation and is observed at relatively high temperatures  $T < 150$  K. Charge transport in the polycrystalline films is similar to electronic transport in PbTe(In) single crystals with highly degenerated electron gas. The persistent photoconductivity is observed at  $T < 25$  K is attributed to contribution of indium impurity centers. Short-duration annealing in oxygen of the n-type polycrystalline films leads to the conductivity type inversion and to formation of grain barriers.

Microstructure of the films strongly affects the photoconductivity character in the terahertz spectral region at wavelengths 90 – 280  $\mu\text{m}$ . All measurements in the terahertz range were performed without screening samples from the thermal background radiation. 100 ns – long laser pulses were used. Different types of photoresponse have been observed. Depending on microstructure of the films and the temperature range, the signal may be positive or negative, of persistent character or just following the laser pulse shape. The positive persistent photoresponse was observed at low temperatures for polycrystalline films. The effect of persistent photoconductivity allowed the tuning of quasi-Fermi level position in the conduction band, and the photoresponse at different level of photoexcitation was studied. Analysis of the experimental data shows the photoexcitation occurs from local electron states in the vicinity of quasi-Fermi level. In the nanocrystalline films, only negative photoresponse is observed. Possible mechanisms of the photoresponse formation in this case are discussed.

### References

[1] D. Khokhlov (ed.), Lead Chalcogenides: Physics and Application (Taylor&Francis, New York, 2003).