Contract No:

This document was prepared in conjunction with work accomplished under Contract No. 89303321CEM000080 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

ELECTROPHYSICAL PROPERTIES OF $Cd_{0.96}Mn_{0.04}Te_{0.96}Se_{0.04}$ CRYSTALS AND SURFACE-BARRIER DIODES

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SRNL-STI-2022-00536

ABSTRACT

$Cd_{0.96}Mn_{0.04}Te_{0.96}Se_{0.04}$ (CMTS) single crystals of p-type conductivity, grown by the Bridgman method in a 3-zone furnace with a rate of 3 mm/hour, were studied. Differential Thermal Analysis (DTA) for this alloy was performed with heating/cooling rates equal to 5 K/min with an intermediate melt dwell time of 30 min. Using the DTA method, the temperatures of the solid-liquid phase transition of $Cd_{0.96}Mn_{0.04}Te_{0.96}Se_{0.04}$ alloys and the melting/solidification rates were determined. From the temperature dependence of the Au/CMTS/Au structure with two ohmic contacts, the resistivity of the semiconductor material was determined, which is equal to $\rho \approx 4\times10^2$ Ω-cm at T = 293 K. The activation energy of the dark conductivity, found from the dependence of the resistivity ρ on temperature, is equal to $\Delta E \approx 0.24$ eV. Using optical measurements of the absorption coefficient from the energy of photons in the region of large α, the band gap was found to be equal E_g = 1.495 eV. Al/CMTS/Au diode structures, fabricated by vacuum deposition of Al on the p-CMTS single crystal surface, were also investigated. A quantitative interpretation of the electrical characteristics of the diodes has been done within the framework of the Saah-Noys-Shockley carrier generation-recombination model.

Key words: $Cd_{0.96}Mn_{0.04}Te_{0.96}Se_{0.04}$, single crystals, ohmic contact, rectifying contact, generation-recombination currents.

The band gap of CMTS single crystals

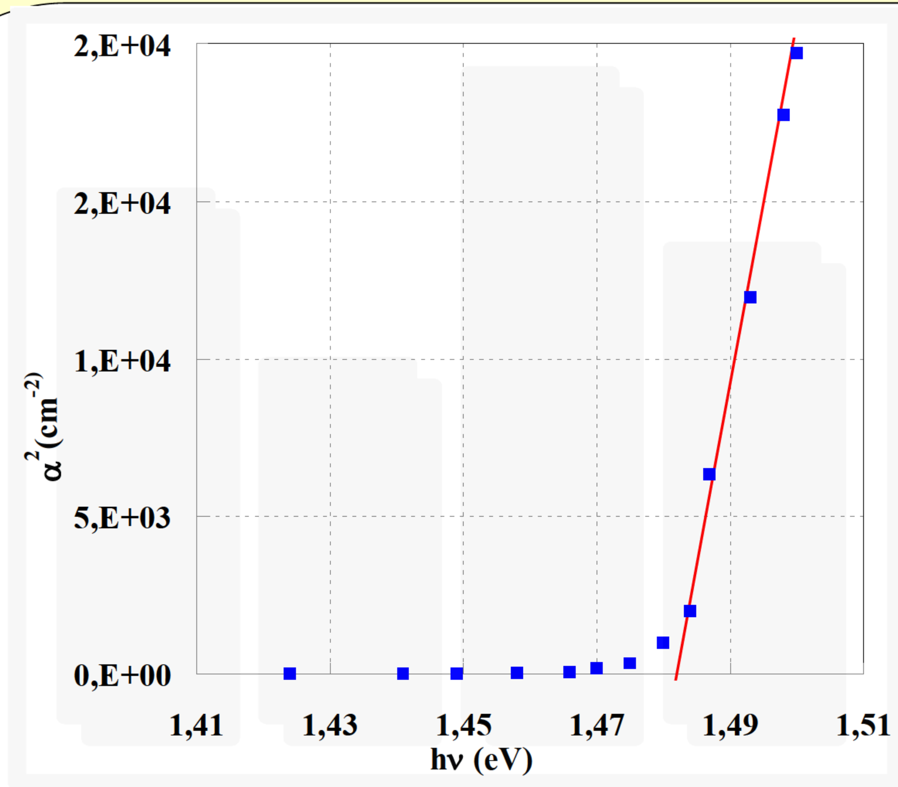

Fig. 1. Optical absorption of a single crystal with a thickness of $d_3 \approx 0.05$ mm in the region of high absorption coefficients at 300 K (filled circles). The solid line is the extrapolation of the linear section to the intersection with the abscissa axis.

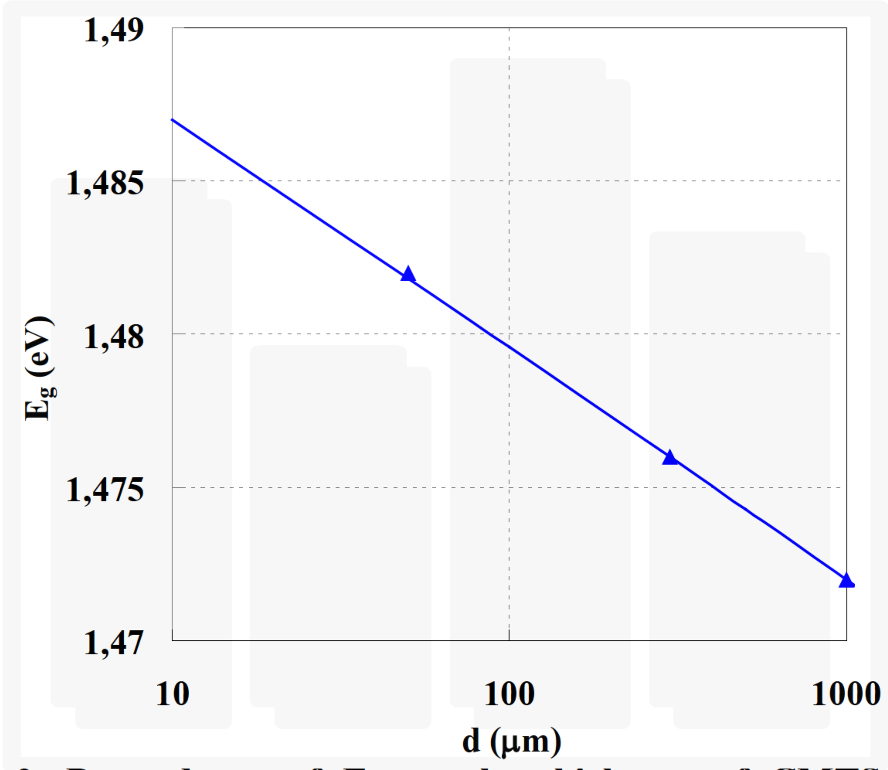

Fig. 2. Dependence of E_g on the thickness of CMTS crystals, determined from the absorption spectra in the region of large values of α. The solid line approximates the dependence E_g=1,495 – 0,0037 ln d, cutting off on the abscissa axis at d=1 μm, the desired value Eg= 1.495 eV.

I-V curve of an Al/CMTS/Au diode

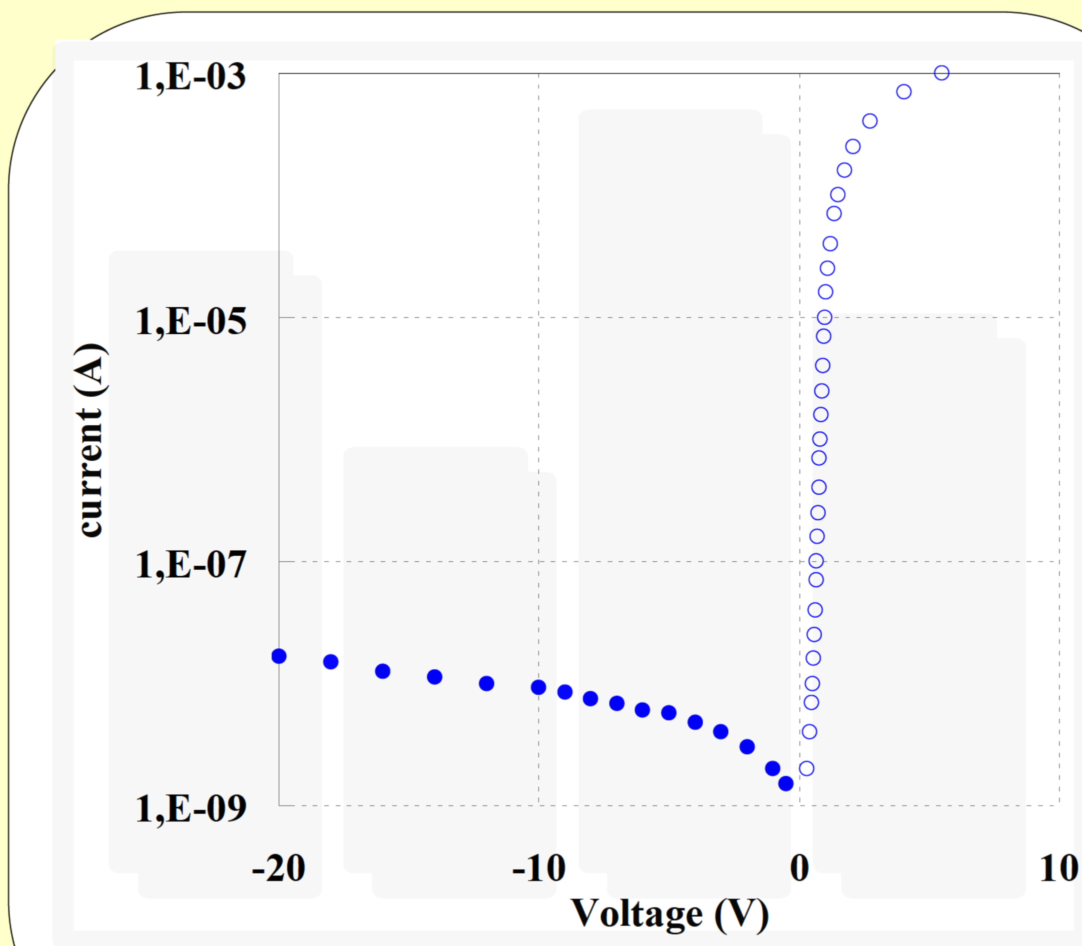

Fig. 3. I-V curve of an Al/CMTS/Au diode at 293 K.

Temperature dependences of the resistivity for Au/CMTS/Au diodes

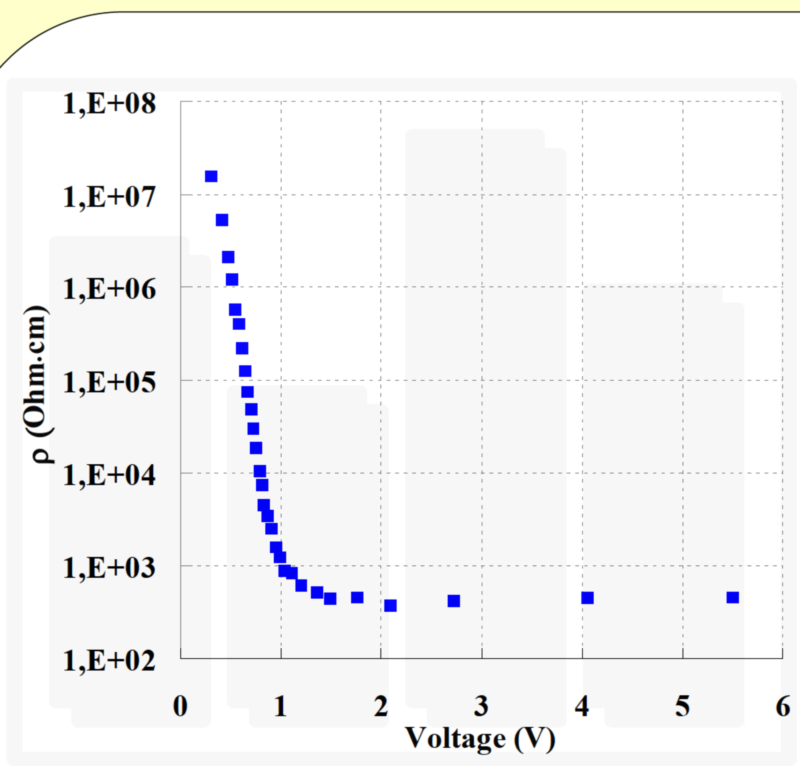

Fig. 4. The dependence of the differential resistance vs. the voltage at forward bias for the Al/CMTS/Au structure at T=293 K.

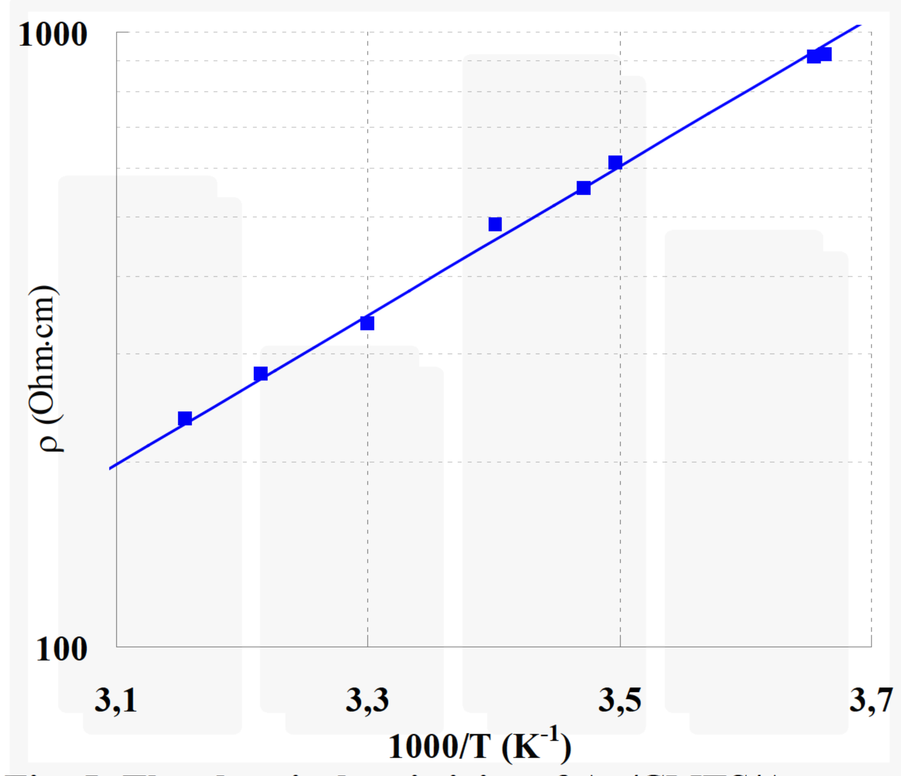

Fig. 5. The electrical resistivity of Au/CMTS/Au vs. temperature. $\rho \approx 4\cdot10^2$ Ohm×cm at T=293 K. Activation energy is $\Delta E \approx 0.24$ eV.

I-V curve of Al/CMTS/Au diode

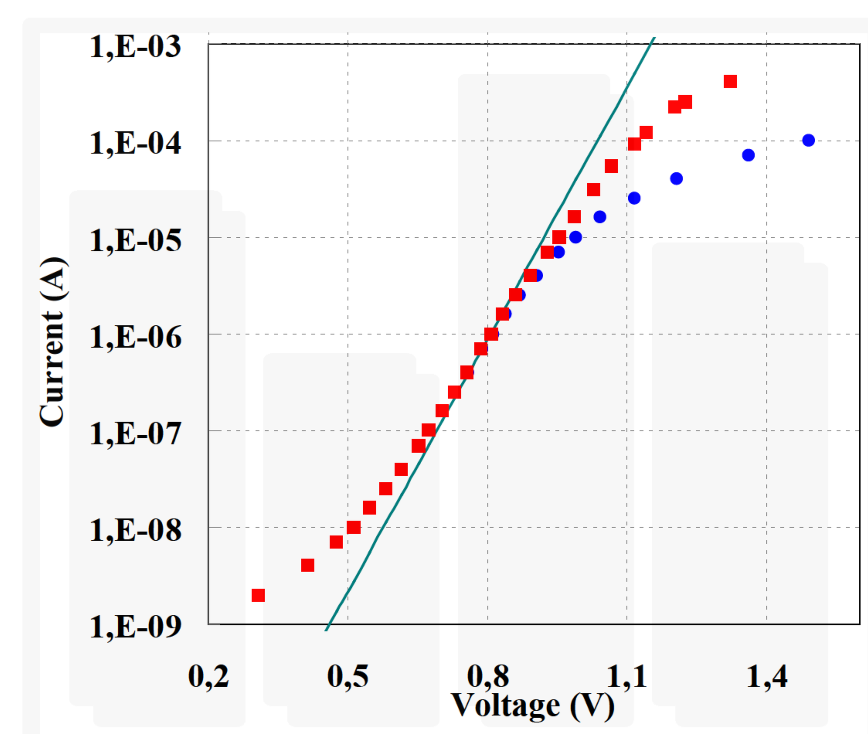

Fig. 6. I-V curve of a Al/CMTS/Au diode at forward bias. Filled circles - without taking into account the voltage drop across the series resistance of the crystal, empty circles - taking it into account. Solid straight line - theoretical dependence $I \sim \exp(eU/2kT)$. T=293 K.

Comparison of the calculated I-V curve with the experiment for the Al/CMTS/Au diode

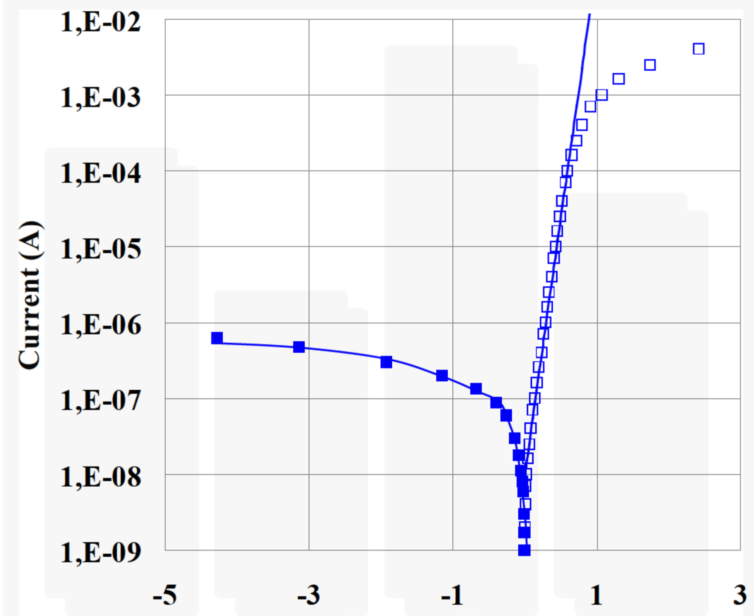

Fig. 5. Experimental I-V curve of the Al/CMTS/Au diode. Filled squares - reverse bias, open squares – forward bias. The solid line is the result of calculations.

$$\upsilon(x,U) = \frac{n(x,U)p(x,U) - n_i^2}{\tau_{po}[n(x,U)+n_1] + \tau_{no}[p(x,U)+p_1]} \quad (1)$$

$$p_1 = \frac{N_v}{\exp\left(\frac{E_g - E_t}{kT}\right) + 1} \quad (2)$$

$$n_1 = \frac{N_c}{\exp\left(\frac{E_t}{kT}\right) + 1} \quad (3)$$

$$n(x,U) = N_c \exp\left[-\frac{E_g - \Delta\mu - \varphi(x,U) - eU}{kT}\right] \quad (4)$$

$$p(x,U) = N_v \exp\left[-\frac{\Delta\mu + \varphi(x,U)}{kT}\right] \quad (5)$$

$$I = Ae\int_0^W U(x,V)dx \quad (6)$$

$$\varphi(x,U) = (\varphi_o - eU)\left(1 - \frac{x}{W}\right)^2 \quad (7)$$

(1) - Generation-recombination rate in the depleted layer
(2), (3) - n_1 and p_1 are numerically equal to the equilibrium concentrations of electrons and holes, provided that the Fermi level coincides with recombination center level.
(4), (5) - n(x,U) and p(x,U) are the concentrations of free carriers in the conduction and valence bands, respectively, n_o and p_o are their equilibrium values, τ_{no} and τ_{po} are effective lifetimes of electrons and holes, respectively, in the depleted region.
(6) - Generation-recombination current density
(7) - The potential energy in the depleted region W. The effective masses of electrons and holes are 0.11m and 0.63m_o, respectively (m_o is the mass of an electron in vacuum), carrier lifetimes in the depletion region of the barrier:

$$\tau_{no} = \tau_{po} \approx 0{,}3\times10^{-9} \text{ s}.$$

The depth of the deep level is taken equal to $E_t \approx 0.75$ eV.

CONCLUSIONS

$Cd_{1-x}Mn_xTeSe$ single crystals were grown by the Bridgman method. According to the DTA data, the melting of the $Cd_{0.96}Mn_{0.04}Te_{0.96}Se_{0.04}$ alloy occurs in the temperature interval of 1363-1378 K. This temperature interval is close to that found for pure CdTe. Superheating above the critical temperature of 1378 K by 25 K was applied to ensure full homogenization of the melt. The band gap of single crystals was found to be E_g = 1.495 eV, and the resistivity of single crystals was $\rho \approx 4\cdot10^2$ Ohm-cm at T=293 K. The Al/CMTS/Au structure had a pronounced diode characteristic and a rectification factor of $K \approx 10^4$ at room temperature. The barrier height, formed during the vacuum deposition of Al on the p-$Cd_{1-x}Mn_xTeSe$ surface, was at least 0.9 eV. The generation-recombination charge transfer mechanism seems to be dominant in the Al/CMTS/Au diodes within the depleted region. The I-V curves of the diodes were quantitatively described in terms of the generation-recombination model of Saah-Noys-Shockley.