Effect of special post-growth treatment on the electro-physical properties of mercury-indium-telluride crystals

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ABSTRACT. The effects of special post-growth treatment (annealing in mercury vapor) on the electro-physical properties of mercury-indium-telluride single crystals were studied. The result of such processing is a 10-100 times decrease in the resistivity of the semiconductor material. Also, the optical transmission coefficient of the material in the Urbach tail area increases significantly. This thermal processing treatment was found to cause a significant improvement in the parameters of the surface-barrier rectifying structures of Cr/*n*-$Hg_3In_2Te_6$/Cr type diodes fabricated using this semiconductor. In particular, a significant decrease in the dark current was observed (approximately 10 times), and the rectification coefficient increased. Diode structures withstood reverse voltages of 200-250 V at moderate values of dark current. For photodiode structures, the dynamic range of the watt-ampere characteristic increased by 10-100 times. This is an encouraging result for the manufacturing of both rectifying and photosensitive diodes from the semiconductor, creating new opportunities to utilize the material's unusually high tolerance to radiation exposure.

Photosensitivity spectra of Cr/*n*-HgInTe/Cr diodes

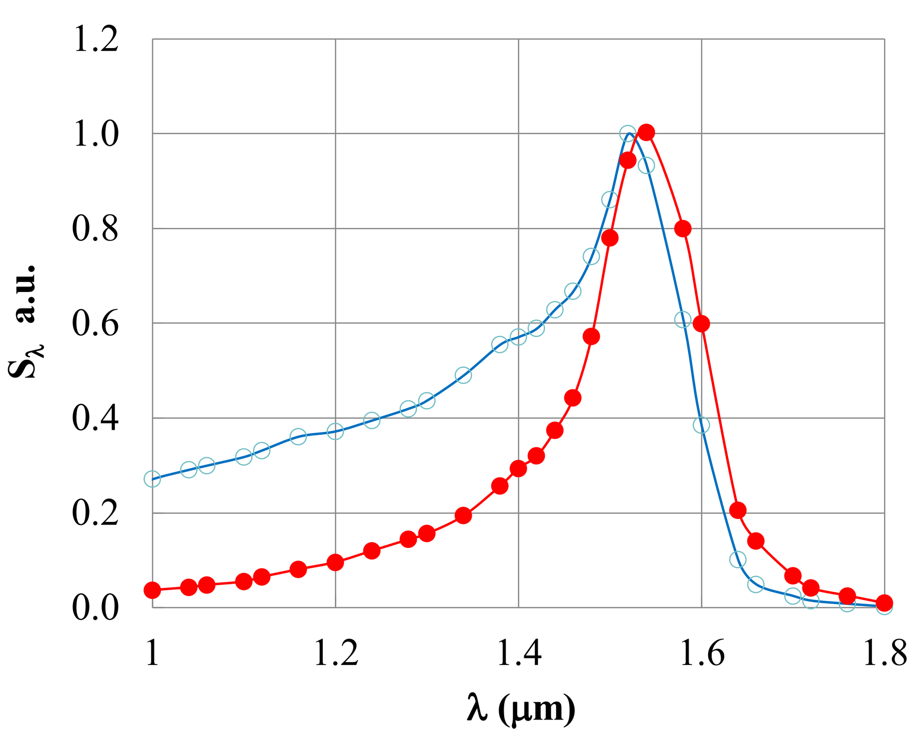

Fig. 1. A typical spectrum of current monochromatic photosensitivity as a function of wavelength for Cr/n-$Hg_3In_2Te_6$/Cr diodes. Filled circles - $\rho \approx 3\cdot10^3$ Ohm cm, unfilled circles - $\rho \approx 10^2$ Ohm*cm. *T*=293 K.

I-V curves of Cr/n-$Hg_3In_2Te_6$/Cr crystals with different resistivity

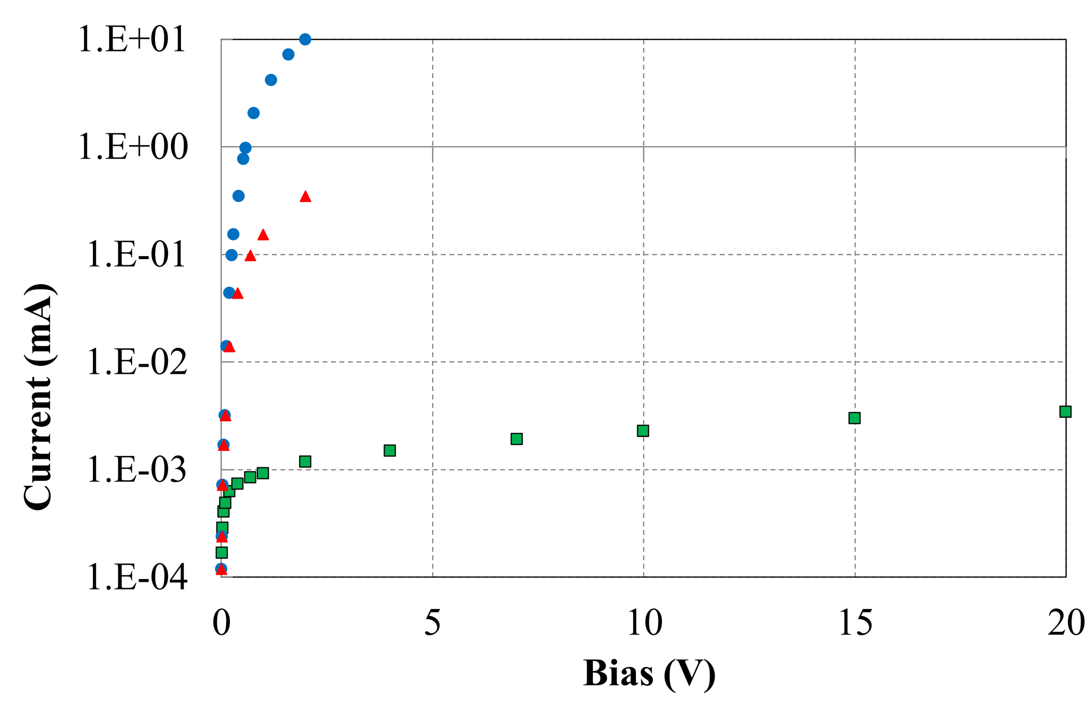

Fig. 2. I-V curves of Cr/*n*-$Hg_3In_2Te_6$/Cr diodes. Forward bias – filled circles ($\rho\approx10^2$ Ohm*cm) and triangles ($\rho\approx 3\cdot10^3$ Ohm*cm). Squares – reverse bias.

Measurement of the *n*-$Hg_3In_2Te_6$ band gap

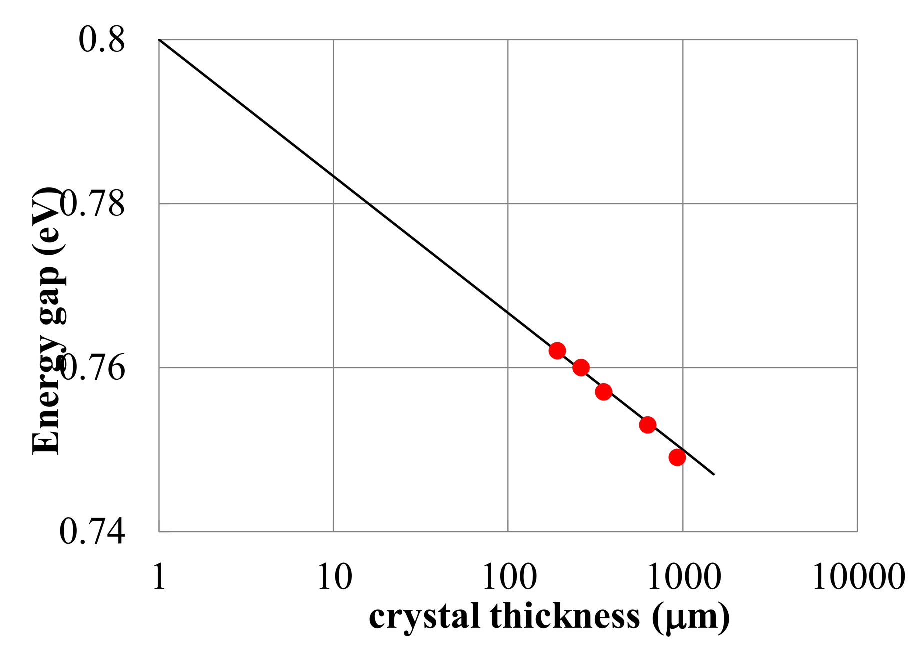

Fig. 3. Comparison of the dependence of the band gap Eg(d) for $Hg_3In_2Te_6$ single crystal with thickness "d" using the formula: E_g=0.80 – 0.067ln *d*, E_g=0.80 – 0.0073ln *d,* T=293K, $\rho \approx 3\cdot10^3$ Ohm*cm.

The band gap and the temperature dependence of the band gap of *n*-$Hg_3In_2Te_6$

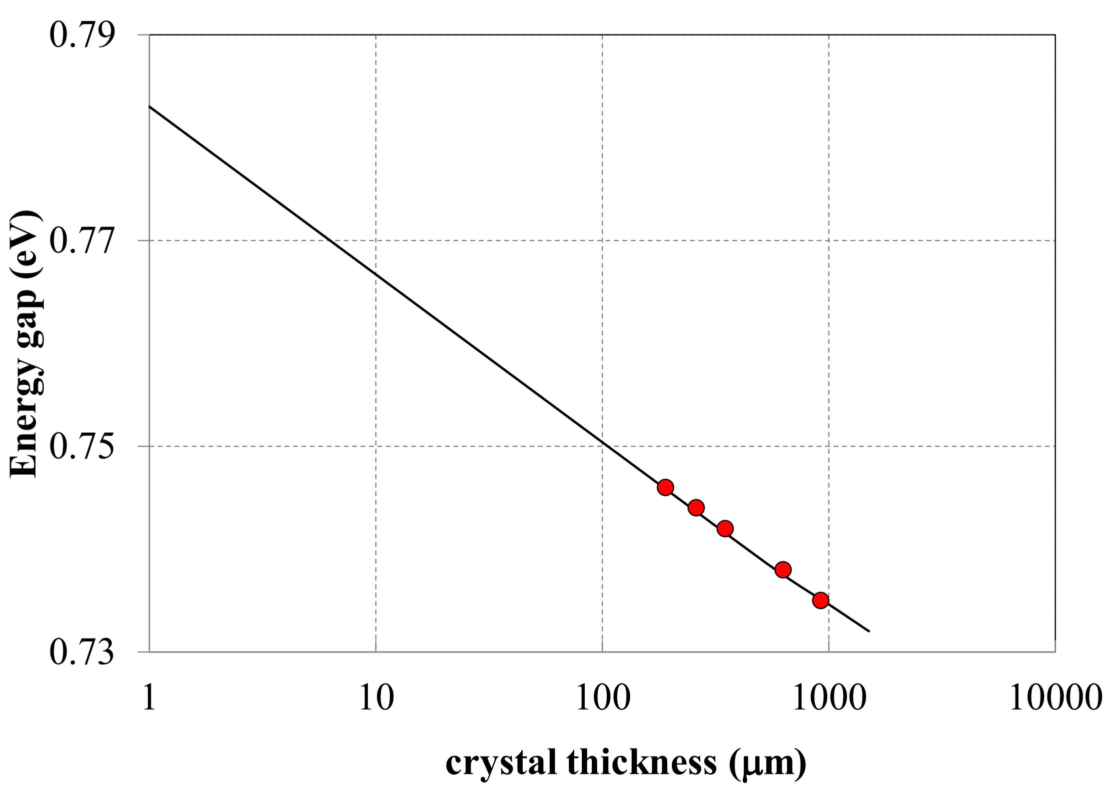

Fig. 4. Comparison of the dependence of the band gap $E_g(d)$ for $Hg_3In_2Te_6$ with crystal thickness d using the formula E_g=0.78 – 0.007ln *d*. T=293K, $\rho \approx 10^2$ Ohm*cm.

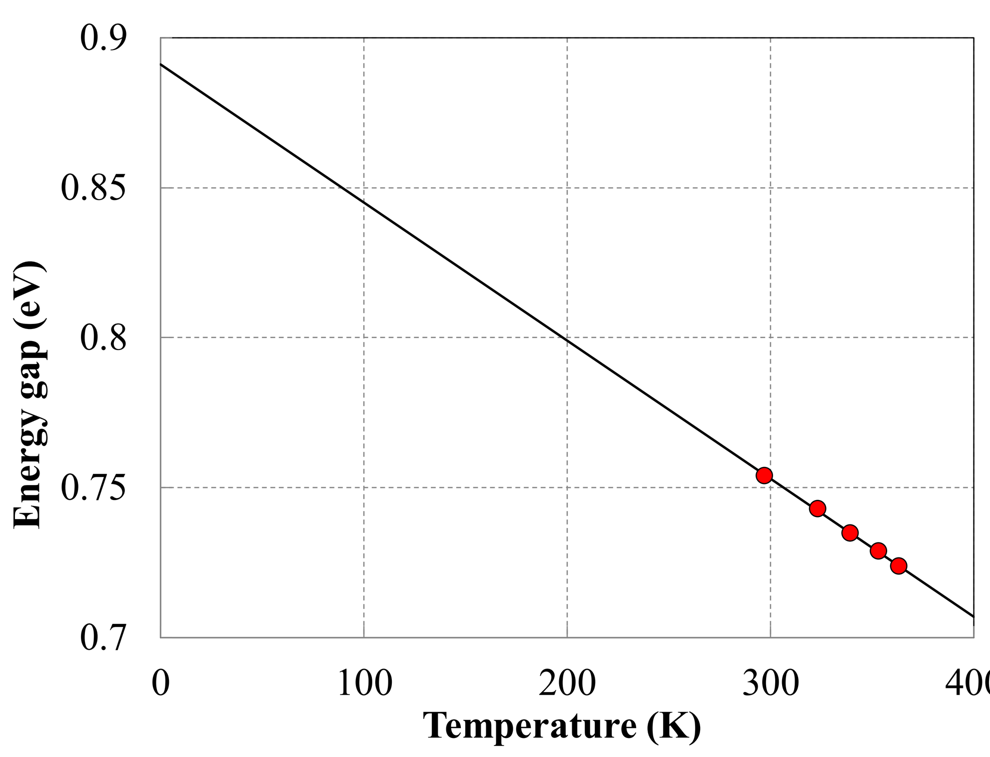

Fig. 5. Dependence of the band gap width $E_g(T)$ vs. temperature for $Hg_3In_2Te_6$. E_g(T)=0.89 – 4.6×10^{-4} K

The technology for growing single crystals of $Hg_3In_2Te_6$, the method for post-growth processing, and the technique to create a rectifying contact were optimized in this study. We investigated the effects of a special post-growth treatment (annealing in mercury vapor) on the electro-physical parameters of mercury-indium telluride single crystals. Following the optimization strategy for growth and post-growth thermal treatment (i.e., annealing in mercury vapor), $Hg_3In_2Te_6$ single crystals with a specific resistance of ρ » 20-200 Ω*cm were obtained. The optical transmission coefficient of the semiconductor material in the Urbach-tail area also increased significantly. The incorporation of improved growth and annealing processes led to a significant improvement in the parameters of surface-barrier rectifier structures of Cr/$Hg_3In_2Te_6$/Cr, opening the door for manufacturing of diodes produced from this semiconductor material.

Topogram and corresponding surface profilogram for fabricating Cr/n-$Hg_3In_2Te_6$/Cr diode

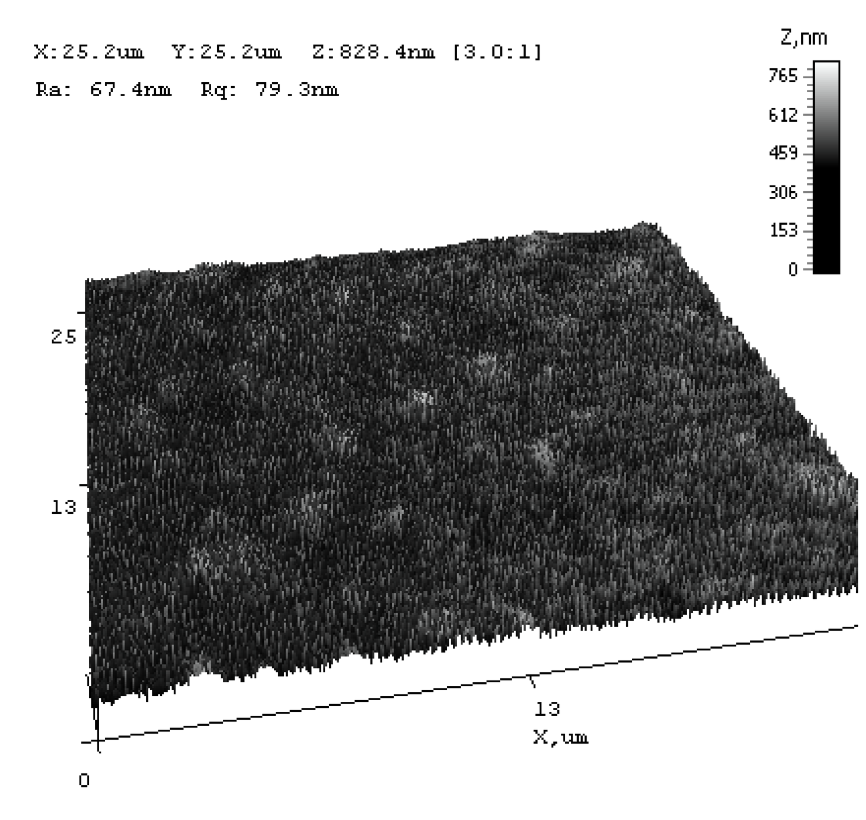

Fig. 6. AFM topogram of the *n*-$Hg_3In_2Te_6$ surface, onto which the rectifying contact was created during optimized processing in an argon plasma.

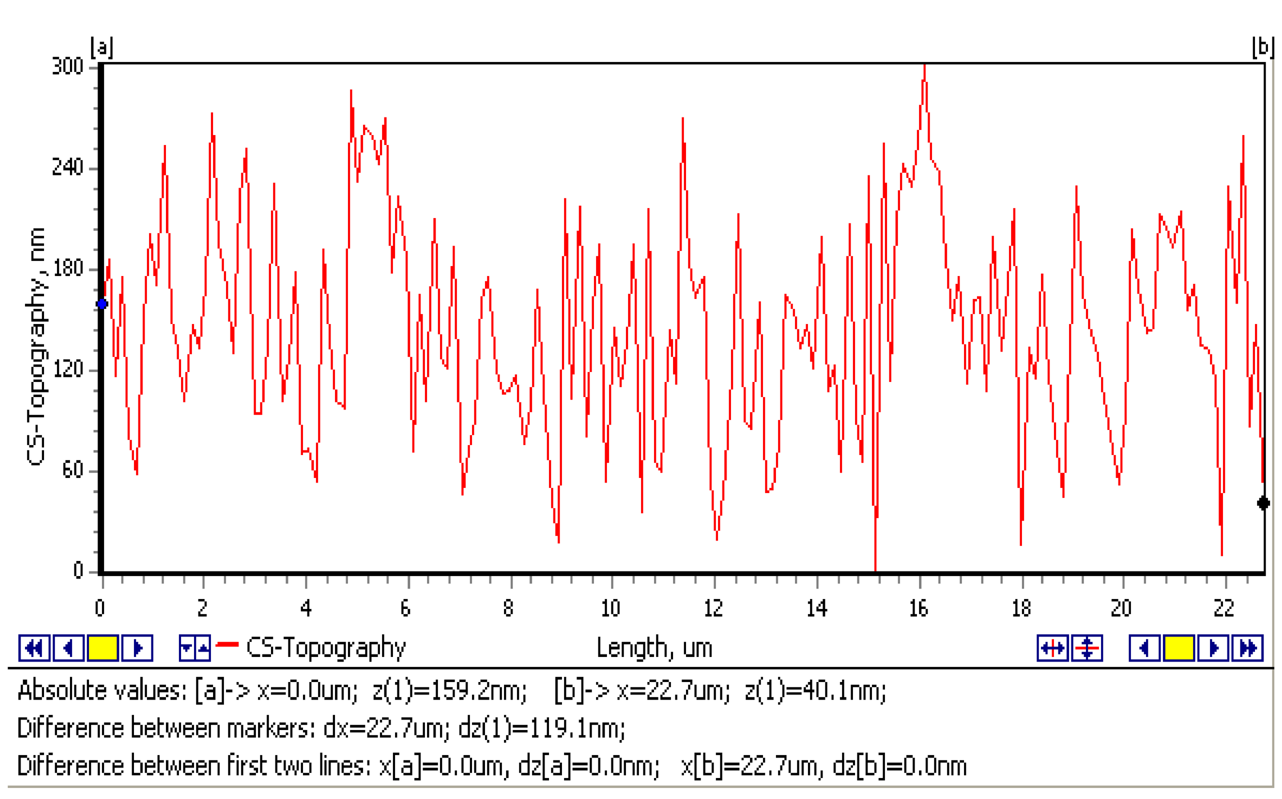

Fig. 7. The corresponding profilogram of the *n*-$Hg_3In_2Te_6$ surface onto which the rectifying contact was formed.

Before applying the appropriate metals as contacts, the surface was treated with argon ions having an energy of 200-500 eV for 10-15 minutes. Processing in an argon plasma before applying metal to form either ohmic or rectifying contacts differed only in the intensity of the ion beam and the duration of the crystal surface-treatment process. We used Cr for the manufacture of diodes with rectifying contact properties, which ensured good adhesion of the metal film to the crystal surface at a relatively moderate substrate temperature, which in our case did not exceed 100-150 °C. The thickness of the chromium film was 10-15 nm, which ensured good transparency and conductivity of the film. To create an ohmic contact, a thin layer of indium was first applied to the opposite surface, and then chromium was applied. The thickness of the indium layer was 10-20 nm, and the thickness of the chromium film was 100-200 nm. Next, the structure was briefly heated for 2-3 seconds to a temperature of 200°C to form a good ohmic contact.

CONCLUSION

The technological methods developed in this study improved the homogeneity of $Hg_3In_2Te_6$ semiconductor material, which make it possible to significantly increase the yield of high-quality diode structures with acceptable parameters. The resistivity of the semiconductor material, the width of the band gap, and the temperature dependence of the band gap were determined. We consider the creation of diodes based on n-$Hg_3In_2Te_6$ that can operate at high voltages to be an important result of our work. This development opens up the possibility of using this material to create rectifier diodes with rectification currents of 10-15 mA that can operate under significant radiation levels. Increasing the dynamic range of the watt-ampere characteristic expands the potential uses of the photodiodes as optical sensors in the near-infrared range, which can provide an important new capability for deployments in high radiation-level environments.

ACKNOWLEDGEMENTS

This work was supported by a grant from the Simons Foundation (Award Number: 1030286). One of the co-authors (R. B. James) acknowledges support by the U.S. Department of Energy, NNSA Office of Defense Nuclear Nonproliferation Research and Development.