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Temperature-dependent characteristics of Pt Schottky contacts on n-type HgInTe

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Abstract
Photodiodes designed to be sensitive in the region 1.4–1.7 μm and obtained by vacuum magnetron sputtering of the Pt layer on the surface of the HgInTe single crystal are studied. Temperature dependence on electrical characteristics of the Schottky diodes was investigated in a temperature range from 120 K to 260 K. The current–voltage characteristics of the diodes show excellent rectification behavior. Temperature dependence on the ideality factor and apparent barrier height was determined, including the effect of series resistance. The ideality factor evaluated was observed to decrease from 2.93 to 1.42, while the flatband barrier height was 0.46 eV in this temperature range. The temperature dependence of the forward characteristics can be well explained by thermionic emission theory. The flatband Schottky barrier height for Pt on $Hg_3In_2Te_6$ is smaller than the value reported for both ITO and Au rectifying contacts on this material. A possible mechanism of the correlation of the ideality factor and barrier height has been proposed.

Mercury indium telluride (MIT) single crystals with a zinc-blende structure have been reported to be promising new photoelectronic material for fabrication of fast and efficient photodetectors, as well as optical filters, efficient visible and infrared radiation sensors, x-ray detectors, temperature sensors, etc [1]. Because of the special feature of the high concentration (about 10^{21} cm^{-3}) of the structural vacancies, the MIT crystal has a number of special properties, such as electrical inactivity of the dopants [2], low defect migration energy [3] and electrical stability to a very high dose of gamma and neutron radiation [4]. The energy bandgap E_g of $Hg_3In_2Te_6$ decreases from 0.757 eV to 0.737 eV when the temperature rises from 12 K to 300 K [5]. For the further development of MIT single crystals, we grew MIT ($x = 0.5$) single crystals. There are some previous reports concerning MIT crystals [6–9]; to our knowledge, few details of Pt/HgInTe Schottky contact and characterizations have been reported until now.

In this work, photodiodes designed to be sensitive in the region 1.4–1.7 μm and obtained by vacuum magnetron sputtering of the Pt layer on the surface of the MIT single crystal are studied. The current–voltage characteristic and its temperature variations are described quantitatively based on the energy diagram and the found parameters of the heterojunction.

HgInTe used in this work was grown by the vertical Bridgman (VB) method. The In composition in HgInTe was determined to be $Hg_3In_2Te_6$ from XRD measurements. The carrier mobility and sheet concentration of the MIT crystal were evaluated by Hall measurements. The photodiodes designed to be sensitive in the region 1.4–1.7 μm were fabricated by vacuum magnetron sputtering of the Pt layer on the surface of the MIT single crystal. Ohmic contacts were fabricated on the MIT surface by evaporating In followed by Au and then annealed at 200 °C in a nitrogen atmosphere to obtain good Ohmic properties. The current–voltage characteristic was measured at 120–260 K. Figure 1 shows the diode structures and the energy diagram of the Pt/HgInTe contact.

The barrier height of the Schottky diodes was evaluated using *I–V* measurements. All the measurements were conducted using a Hewlett Packard 4140B picoampere meter in the temperature range from 120 K to 260 K in a dark chamber with a vacuum of 8×10^{-3} Torr.

Figure 2 shows the forward *I–V* characteristics of the Pt/HgInTe Schottky diodes measured at different temperatures. The excellent rectification behavior of the Schottky diode is observed in the measured temperature range. The forward biased *I–V* relationship shown in figure 2 can

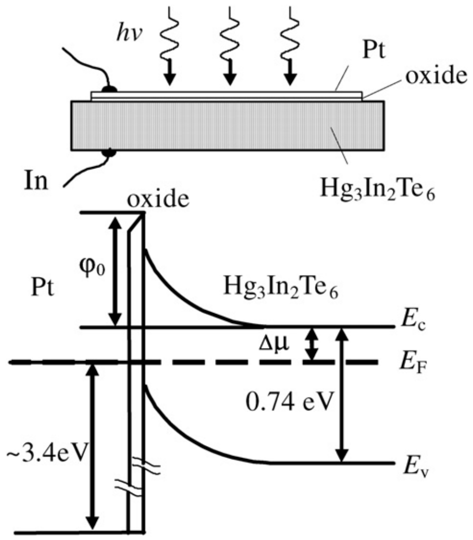

Figure 1. Structure and energy diagram of the Pt/HgInTe contact.

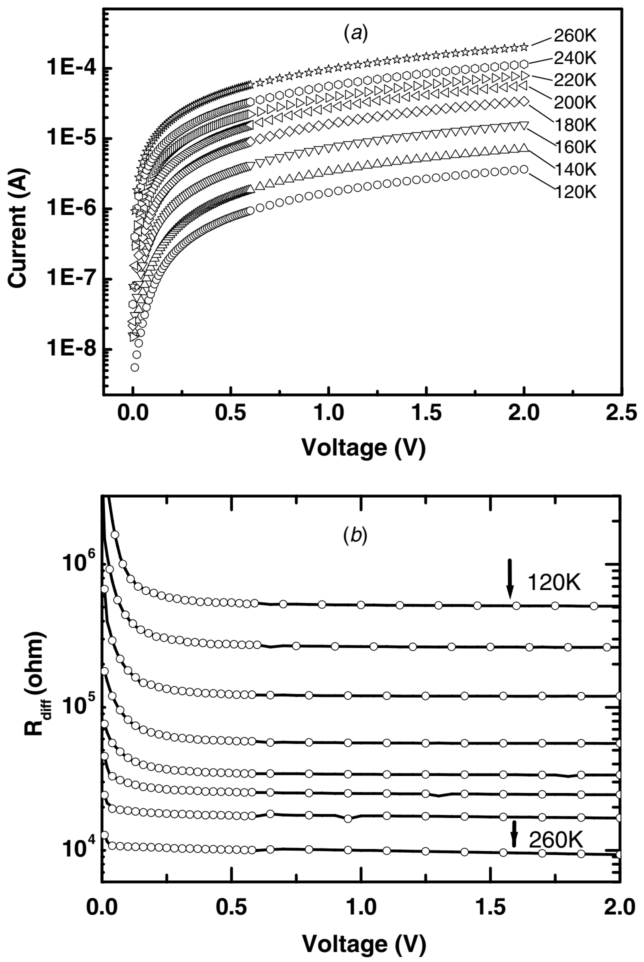

Figure 2. (*a*) *I–V* characteristics and (*b*) differential resistance of the Pt/HgInTe Schottky diode at various temperatures (from top to bottom: 120, 140, 160, 180, 200, 220, 240, 260 K).

be given by the following equation based on the thermionic emission model:

$$I = I_s \exp\left(\frac{qV}{nkT}\right)\left(1 - \exp\left(-\frac{qV}{kT}\right)\right), \qquad (1)$$

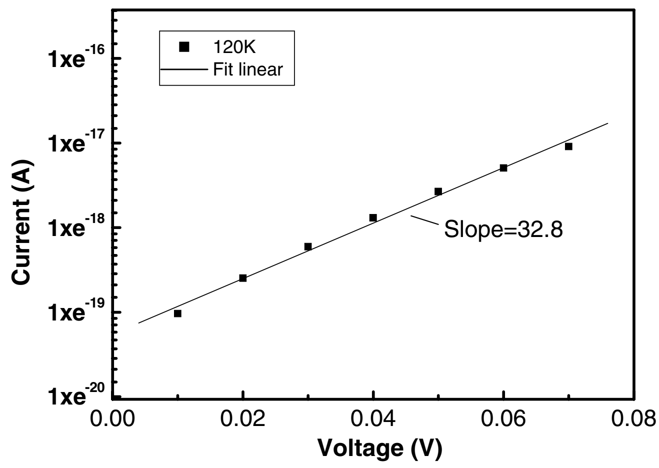

Figure 3. ln *I* versus *V* for the Pt/n-HgInTe Schottky diode at 120 K.

where n is the ideality factor and I_s is the saturation current:

$$I_s = AA^*T^2 \exp\left(-\frac{\varphi_0 + \Delta\mu}{kT}\right). \qquad (2)$$

V is the applied voltage, A is the Schottky contact area and A^* is the effective Richardson constant defined by $A^* = 4\pi q m_n^* k^2 h^{-3}$, where $m_n{}^*$ is the effective mass of the electron in the semiconductor, φ_0 is the barrier height on the side of the $Hg_3In_2Te_6$ crystal in the equilibrium and $\Delta\mu$ is the energy gap between the Fermi level E_F and the conduction band bottom in the bulk part of the diode. So, from the energy diagram, the potential barrier height at the contact on the Pt side is $\Phi_B = \varphi_0 + \Delta\mu$.

In addition, we modeled the ideality factor in order to gain insight into the conduction mechanisms. Under low current injection, the effect of series resistance is negligible; thus, for $3kT/q \ll V$, equation (1) can be written as

$$\ln I_f = \ln I_s + \frac{qV}{nkT}, \qquad (3)$$

where I_f is the forward current. The ideality factor n and the saturation current I_s were obtained by fitting the forward *I–V* curve to equation (3) [10]; this yields an ideality factor of $n = 2.93$ at 120 K for this diode as shown in figure 3. We then get the ideality factor value in the temperature range from 120 K to 260 K. This is shown in figure 4. It can be seen that the ideality factor decreases as the temperature increases ($n = 2.93$–1.42 as $T = 120$–260 K). The ideality factor n has a value between 1 and 2. If n is closer to 1, then diffusion current dominates; however if n is closer to 2, recombination current dominates. However, our value of n, which is almost 3, falls outside this expected range. It could be caused by the interfacial layer and surface states [11].

In order to determine the value of the barrier height Φ_B, equation (2) can be written as

$$\ln(I_s/T^2) = \ln(A \cdot A^*) - \Phi_B/kT. \qquad (4)$$

The saturation current, I_s, was obtained from *I–V* measured at various temperatures (120–260 K). The barrier height Φ_B was determined by

$$\Phi_B = -1000k\frac{\Delta(\ln(I_s/T^2))}{\Delta(1000/T)}. \qquad (5)$$

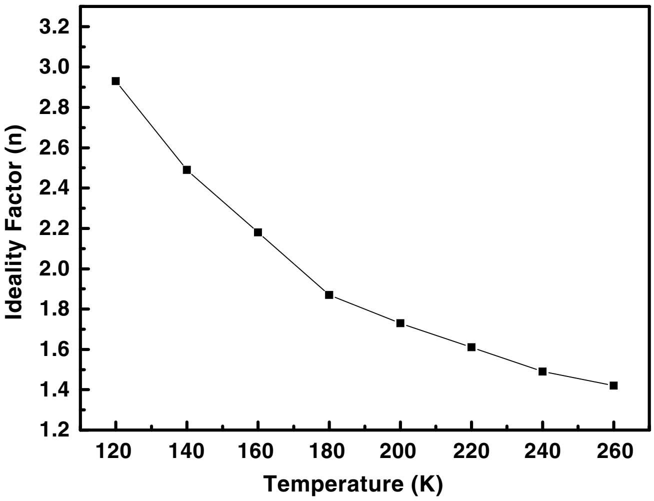

Figure 4. Temperature dependence of ideality factor for the Pt/HgInTe Schottky diode.

The barrier height is obtained from equation (5). The value of Φ_B is 0.36 eV. The measured value of Φ_B is smaller than the theoretical value. Such a discrepancy was also observed on Ag/ZnO Schottky diodes [12], where it was attributed to the electrons tunneling through a barrier. The nonideal characteristics of the Schottky diode can also be caused by Schottky barrier inhomogeneity. For nonideal Schottky diodes, a more meaningful barrier height, the flatband barrier height Φ_{BF}, is used by modifying the measured barrier height, Φ_B:

$$\Phi_{BF} = n\Phi_B - (n-1)\frac{kT}{q}\ln\left(\frac{N_C}{N_D}\right), \qquad (6)$$

where n is the ideality factor, N_C is the effective density of states in the conduction band and N_D is the donor concentration. At 260 K, the theoretical value of N_C is calculated to be 3.5×10^{13} for HgInTe. The flatband barrier height is then determined to be 0.46 eV using equation (6).

The value $\Delta\mu$, which is necessary to construct the energy diagram of the diode, can be determined from the temperature dependence of the resistivity ρ of the material. Using $R_s = \rho\frac{l}{A}$, we can easily find the resistivity from R_s, the diode area A (0.188 mm^2) and the substrate thickness (0.85 mm). The expression for ρ can be written as

$$\rho = \frac{1}{q\mu_n n} = \frac{1}{q\mu_n N_C \exp(-\Delta\mu/kT)}. \qquad (7)$$

In figure 5, the slope of the straight line in the coordinates ln ρ versus $1000/T$ yields the Fermi level energy $\Delta\mu$. The value of $\Delta\mu$ equals 0.076 eV.

In summary, Pt/MIT Schottky diodes with excellent rectification properties have been fabricated. The temperature dependence on the Schottky diodes has been investigated and can be well explained by thermionic emission theory. Temperature dependence on the ideality factor was determined, including the effect of series resistance. The ideality factor evaluated was observed to decrease from 2.93

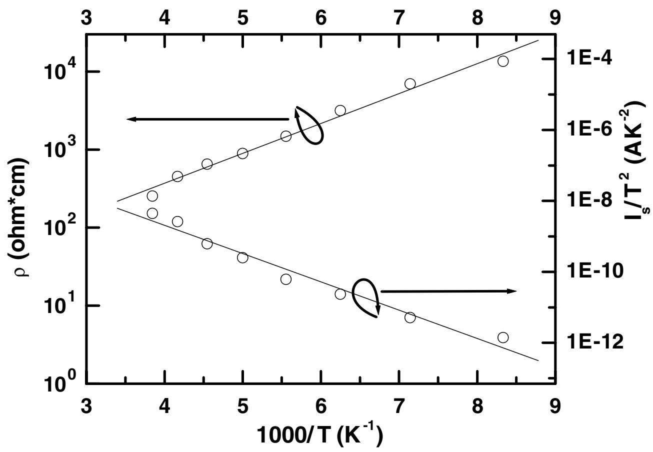

Figure 5. Plot of $\ln(I_s/T^2)$ and ln ρ versus $1000/T$.

to 1.42, while the flatband Schottky barrier height is 0.46 eV at 260 K. The measured barrier height for Pt on $Hg_3In_2Te_6$ is smaller than the value reported for both ITO and Au rectifying contacts on this material.

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