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ADMITTANCE CHARACTERISTICS OF NARROW GAP Hg$_{1-x}$Cd$_x$Te n-p-n AND p-n-p TRIPLE LAYER STRUCTURES

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Abstract

The anomalous admittance properties of the narrow gap Hg$_{1-x}$Cd$_x$Te n-p-n and p-n-p triple layer structures are reported and investigated. The admittance for this triple layer structure is calculated by the use of a simplified theoretical model. The possibility of making a new kind of infrared detector by use of these particular properties is also discussed.

1. Introduction

In the last few years there has been considerable interest in the narrow gap HgTe-CdTe superlattice and some other II-VI compound semiconductor superlattices. These materials are very important for making infrared detectors. We have found it possible to make thin layer structures by the ion-implantation technology.

Anomalies were observed when we worked on Phosphorus(P) ion implanted and Mercury(Hg) or Mercury-Indium(Hg-In) diffused Hg$_{1-x}$Cd$_x$Te p-n junctions, which are invalid for the current p-n junction theory. Phosphorus atoms in Hg$_{1-x}$Cd$_x$Te are acceptors[1], after being annealed the phosphorus implanted N-type Hg$_{1-x}$Cd$_x$Te may form p-on-n junction. But the fact is that the damaged surface layer due to the P-ion implantation has an n-type conductivity.[2] So the phosphorus ion implantation into n-type Hg$_{1-x}$Cd$_x$Te may form n-p-n triple layer structures.

Hg interstitial atoms in p-type Hg$_{1-x}$Cd$_x$Te are donors[3], the diffusion Hg may form an n-on-p junction. But after being annealed at a certain temperature and Hg pressure, a p-type layer in n-type surface will be observed. Therefore, the Hg diffusion into p-type Hg$_{1-x}$Cd$_x$Te may form a p-n-p triple layer structures.

In experiments, we discovered that there is an apparent abrupt change in capacitance-temperature relation of the P-ion implanted and Hg diffused Hg$_{1-x}$Cd$_x$Te p-n junctions. In this paper, the experimental results are shown. A theoretical analysis and calculation are carried out by the use of a simplified admittance model of the triple layer structure. We also analyse the possibility of making a new kind of Hg$_{1-x}$Cd$_x$Te thermoelectrical infrared detector making use of the capacitance and conductivity abrupt change properties.
2. Experimental methods and results

Fig. 1 Conductance-voltage curves for different temperatures for a phosphorus-implanted Hg_{1-x} Cd_x Te (x=0.275) n-p-n triple structure device.

Fig. 2 Capacitance versus voltage for different temperatures for an x=0.275 Hg_{1-x} Cd_x Te n-p-n triple structure device.

We used a non-equilibrium capacitance bridge, which consists of an EG&G M5202 High frequency Lock-in Amplifier, for admittance measurement. We also used an HP 4275 LRC meter to measure the capacitance for Hg_{1-x} Cd_x Te triple layer structures. Fig. 1 and Fig. 2 show the G-V and C-V curves for different temperatures for a phosphorus-implanted Hg_{1-x} Cd_x Te n-p-n triple structure device, respectively. Fig. 3 shows the C-T and G-T relations for the same device. It is interesting that there is an abrupt change in capacitance near 166K. We can also see from Fig. 1 and Fig. 2 that the capacitance and the conductance anomalies occur near 170K. The experimental results in Fig. 1 and Fig. 2 are measured by an M5202 high frequency amplifier. The results which are shown in Fig. 3 are obtained by an HP 4275LRC meter. The capacitance-voltage characteristics for different frequencies for an Hg_{1-x} Cd_x Te (x=0.2) p-n-p triple structure device are shown in Fig. 4.

3. Theoretical model for the admittance of Hg_{1-x} Cd_x Te triple layer structures.

Under the condition of a small alternating signal, a semiconductor n-p-n or p-n-p triple layer structure can be simplified to a series of the two p-n junctions. On the basis of the theory of resistance-capacitance network [4], we obtained the expression for the admittance of the n-p-n (or p-n-p) triple layer structure.

The total conductance for the semiconductor n-p-n (or p-n-p) triple layer structure is given by

$$G_{(total)} = \frac{G_1 G_2 + G_1 G_3 + w^2 C_1 G_2 + w^2 C_2 G_1}{(G_1 + G_3)^2 + w^2 (C_1 + C_2)^2}$$

The total capacitance for this structure is given by

$$C_{(total)} = \frac{C_1 G_2^2 + C_2 G_1^2 + w^2 C_1^2 C_2 + w^2 C_2^2}{(G_1 + G_3)^2 + w^2 (C_1 + C_2)^2}$$
Fig. 3 Capacitance versus temperature and the conductance versus temperature for a \( x=0.275 \) \( \text{Hg}_1-x \text{Cd}_x \text{Te} \) n-p-n triple structure device.

Fig. 4 Capacitance-voltage characteristics for different frequencies for a \( \text{Hg}_1-x \text{Cd}_x \text{Te} (x=0.2) \) p-n-p triple structure device. 
\( \triangle - f=1 \text{MHz}, \; \bigcirc - f=3 \text{MHz}, \; \bullet - f=10 \text{MHz}. \)

Where \( C_1 \) and \( G_1 \) are the capacitance and conductance for the first p-n junction, respectively. \( C_2 \) and \( G_2 \) are the capacitance and conductance for the second p-n junction, respectively. \( \omega \) is the measuring frequency.

Fig. 5 The theoretical calculation for capacitance versus temperature on a \( \text{HgCdTe} (x=0.275) \) n-p-n triple layer structure. Solid line-taking account of deep level to band tunneling capacitance. Dotted line-taking no account of deep level to band tunneling capacitance.

The expression for the capacitance and conductance of the p-n junctions with regard to the effect of deep levels can be seen in Ref. 5. The total conductance and the total capacitance for the Ge
p-n-p triple layer structures are calculated by equation (1) and (2). The theoretical calculations are in good agreement with the experimental results.\[5\]

The capacitance versus temperature for a narrow gap Hg$_{1-x}$Cd$_x$Te (X=0.275) n -p-n triple layer structure are calculated. The theoretical calculations are in good agreement with the experimental results. The theoretical results shown in Fig.5 are very similar to the experimental results shown in Fig.3. These findings lead us to the conclusion that the abrupt change for the capacitance of an HgCdTe n-p-n triple layer structure results from the deep level to band effect of the p-n junction.

4. Discussion

The frequency effect for the X=0.2 Hg$_{1-x}$Cd$_x$Te p-n-p triple layer structure is investigated and analysed. The experimental results are shown in Fig.4. As a result of theoretical calculation we find out that the frequency for the capacitance of the p-n-p (or n-p-n) triple layer structure have an important bearing on the diffusion capacitance and the deep level to band capacitance of p-n junctions.

From the experiments we can see that near the capacitance abrupt change region of the Hg$_{1-x}$Cd$_x$Te n -p-n triple layer structure, the temperature coefficient of conductivity $\alpha_c$ =0.76 and that of capacitance $\beta_c$ =0.24-0.28 are one order larger than those of an ordinary thermistor with $\alpha_c$=0.04. On the basis of these particular characteristics we have designed a new kind of infrared detector. The calculations shown that the detectivity of this kind of thermoelectrical infrared detector will be one order's larger than those of the general thermistor. Changing the composition X of Hg$_{1-x}$Cd$_x$Te, we can obtain this kind of detector, which could operate at room temperatures. We have also observed some interesting phenomena related to the optical response of the Hg$_{1-x}$Cd$_x$Te p-n-p triple layer structure.

References

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