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Impedance Spectroscopy of Au–CdTe:Ga Schottky Contacts

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The dielectric response of Au–CdTe gallium doped Schottky contacts was investigated by impedance spectroscopy in the frequency range from 0.2 Hz to 3 MHz, at temperatures in the range from 77 K to 300 K. Combined modulus and impedance spectroscopic plots were analyzed to study the response of the structure. The data were fitted with the simple RC circuit composed of a depletion layer capacitance in parallel with resistance and a series resistance of the bulk CdTe:Ga. The activation energy of the bulk trap obtained from the Arrhenius plot of the resistance was found to be equal to 0.08 eV, close to the value 0.09 eV obtained from the impedance-modulus spectroscopy. The trap dominant in CdTe:Ga is possibly the DX center related, as it has been observed that this is the dominant trap in the material.

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1. Introduction

Deep level transient spectroscopy (DLTS) and admittance spectroscopy are widely used techniques suitable to study properties of deep traps controlling operation of semiconducting devices. Recently the complex impedance spectroscopy (IS) has become popular as an alternative experimental technique in this context, for it conveys information about trapping transitions on frequency. IS records the response of a system to a small ac signal. The applied ac voltage and ac current are measured and impedance calculated. The current in the ideal case of a simple RC circuit probed by the ac voltage has the same frequency ω as the applied ac voltage but it is shifted in phase and has different amplitude. In order to analyze and interpret experimental data for investigated junction it is essential to find a model equivalent circuit that provides realistic representation of the electrical properties.

The complex impedance Z^* and complex modulus M^* are the most frequently used representation of the complex data. It can be shown that for a simple parallel RC circuit, complex impedance and modulus are interrelated [1]:

$$M' + \mathrm{j}M'' = \mathrm{j}\omega C_0 Z^* = \mathrm{j}\omega C_0(Z' - \mathrm{j}Z'') = \omega C_0 Z'' + \mathrm{j}\omega C_0 Z', \tag{1}$$

where M' (Z') are the real, and M'' (Z'') imaginary modulus (impedance) terms. C_0 is the vacuum capacitance of the sample holder and electrode arrangement. Detailed consideration of Eq. (1) shows that Z'' and M'' have the same functional form, giving rise to a Debye peak when plotted against frequency. The peaks have different weighting factors for the Z'' peak is scaled according to R whereas the M'' peak is scaled according to C^{-1}:

$$Z'' = R\left[\frac{\omega RC}{1+(\omega RC)^2}\right], \qquad M'' = \frac{C_0}{C}\left[\frac{\omega RC}{1+(\omega RC)^2}\right]. \tag{2}$$

The peaks on the spectra of $\log Z''$ or $\log M''$ plotted against frequency $\log f$ appear at the same frequency

$$\omega_{\max} = \frac{1}{RC} = \tau^{-1}. \tag{3}$$

If the time constant has its origin in the process which is thermally activated, the Arrhenius plot of τ yields its activation energy.

In the impedance and modulus complex plane plots, a parallel RC circuit results in a single semicircle. From the intercept of arc with real axis of the impedance (modulus) plot the value of R (C) can be extracted. The arcs possess maximum at the frequency given by Eq. (3). The activation energy can be also obtained from the Arrhenius plot of $\log R$ versus $1/T$ dependence.

In this study IS was applied to measure the parameters of CdTe:Ga Schottky diodes. The spectroscopic plots revealed that the major response was due to the bulk. The complex impedance and modulus plots have shown data points lying on a single semicircle, implying that the response originates from a single capacitive element corresponding to the depletion region of the junction. Based on the plots the activation energy of the bulk trap was determined.

2. Experimental details

The samples of gallium doped CdTe were processed by the Bridgman method. Prior to the measurements, the sample wafers were annealed in cadmium vapors, mechanically polished and subsequently etched in 2% Br_2 in methanol solution. Ohmic contacts were produced by soldering indium onto the fresh backside surface. Gold Schottky contacts were thermally evaporated on the front side of the samples. Capacitance–voltage measurements yielded the net donor concentration at 300 K on the order of 10^{17} cm^{-3}. The dielectric properties were measured using Novocontrol impedance analyzer and a PC with the data acquisition. Data evaluation software Solartron Z-plot was used. The ac probe signal amplitude equal to 10 mV was applied. Measurements were performed in the frequency range from 0.2 Hz to 3 MHz, at temperatures in the range from 77 K to 300 K.

3. Results and discussion

In Fig. 1 the plot of the imaginary impedance $Z''_{\rm s}$ as a function of frequency of the probing ac voltage at different temperatures is shown. The impedance exhibits a single maximum shifting toward lower frequency with decreasing temperature. The maximum scales with parallel resistance of the circuit (cf. Eq. (1)), hence it can be noted that R is temperature dependent.

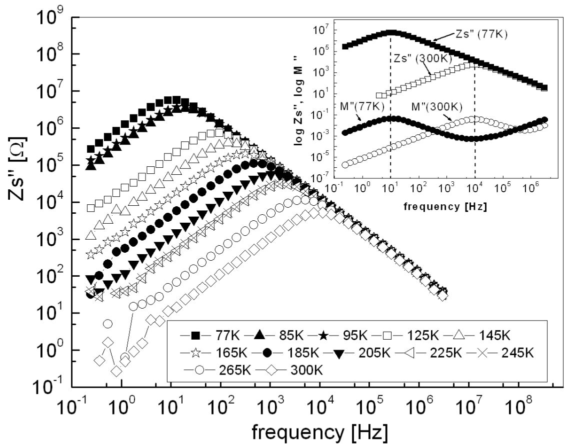

Fig. 1. Double-logarithmic imaginary impedance versus frequency plots taken at different temperatures.

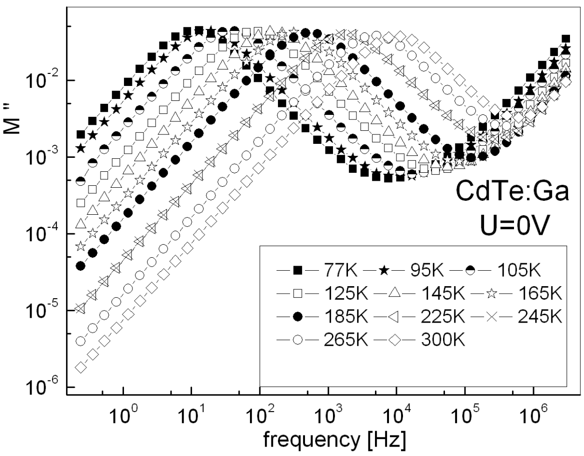

Fig. 2. Double-logarithmic imaginary modulus versus frequency plots measured at different temperatures.

In Fig. 2 a similar plot of the imaginary modulus M'' is given. The modulus also exhibits maximum shifting toward lower frequency with decreasing temperature. As modulus scales with capacitance C, the constant height of the modulus peak means that capacitance barely changes with temperature.

In the inset of Fig. 1 the modulus-impedance vs. frequency plots are shown to point out that they peak at the same frequency irrespective of temperature.

In Fig. 3a and b sample complex impedance and modulus plane plots are drawn for different temperatures. The plots are semicircles indicating a pure Debye type of response.

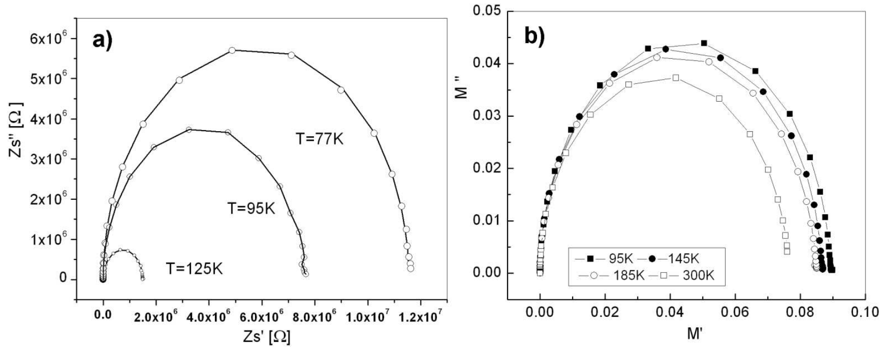

Fig. 3. (a) Complex impedance plane plot. (b) Complex modulus plane plot.

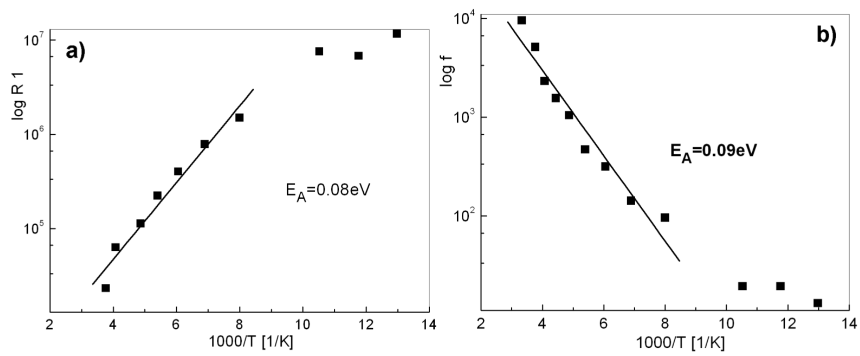

Fig. 4. (a) Arrhenius plot of R1. (b) Arrhenius plot of modulus and impedance peaks.

In Fig. 3a open circles stand for the experimental data, solid lines stand for the fitting with a circuit shown in the inset. The parameters $R1$, $R2$ and C have been determined from the fitting. The resistance $R2$ decreases from the value of 14 Ω at 77 K to 4 Ω at 300 K whereas capacitance increases from 1.3×10^{-9} F to 1.5×10^{-9} F, respectively. The resistance $R1$ is thermally activated. In Fig. 4a and b the Arrhenius plots of $R1$ and of the frequency corresponding to the peaks of impedance and modulus given in Fig. 1 and in Fig. 2 are shown. Both Arrhenius plots yield close value of the activation energy ≈ 0.08 eV. The presence of a single semicircle signifies the dominance of the depletion region of the Au--CdTe:Ga Schottky barrier without the effect of any other capacitive elements.

It can be assumed therefore that the trap located within the depletion region of the junction manifests in the relaxation processes. The dominant deep trap in $Cd_{1-x}Mn_xTe$:Ga is the metastable DX center, related to gallium [2]. In the case of CdTe:Ga the same origin of the dominant trap is expected [3]. The presence of metastable defects in the studied samples has been confirmed by observation of persistent photoeffects [4].

4. Conclusions

The complex impedance spectroscopic technique was used to characterize relaxation processes in Au–CdTe:Ga Schottky barriers. The ac impedance data imply that the observed dielectric responses can be described by an equivalent circuit consisting of a parallel resistance $R2$ and capacitance C in series with a resistance $R1$. Bulk trap of activation energy of 0.08 eV was found and it was attributed to the dominant DX related trap.

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