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Influence of the metallic contact surface area on the low-frequency noises of metal-semiconductor contacts

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Abstract - CVC and low-frequency noises of metal-semiconductor contacts at the room temperature have been researched when the current flows through volume and surface of the samples. We investigate CVC and low-frequency spectra of diode structures with one Schottky barrier and with double oppositely offset barriers made on Cr/*n*-Si, W/*n*-Si contacts. It is shown that CVC and the level of the noises strongly depend on the surface area of the metallic contacts. The Physical processes taking part in the volume and surface of this structures which are influences on the behavior of low-frequency noises, are also presented. It is show that for decreasing of the low-frequency noises' level it is more reasonable to use contacts with small surface area.

Keywords: low-frequency noise, metal-semiconductor contact, Schottky barrier

1. Introduction

The work principle of the Schottky diodes is based on the transfer of the majority carriers. There are no charge accumulations of minority carriers in the Schottky contacts, therefore they are preferable in use as high–frequency diodes [1]. Metal-semiconductor contacts are used to make high-speed Schottky diodes. Schottky contacts are widely used in the output stages, impulse switching power supplies of computers, servers and data communications as well as in modern mobile wireless devices and other units of electronic equipments [2, 3]. Due to the best timing response and low junction capacitance, rectifiers Schottky diodes differ from other diodes by low noise level, which makes them the most preferred for use in switching power supply [4,5].

The roles of the processes occurring in the boundary of semiconductor with other materials (metals, dielectrics, electrolytes, gases) are currently under intensive studies [5-8]. There are metallic electrodes in electronic devices which are applying for different purposes. From this point here is a great interest to study the effect of different metals contact with semiconductors on the electrical parameters of the metal-semiconductor contacts. Investigations show that the main operating parameters of these structures depend not only from the choice of the semiconductor, but also on the nature of the contact metal materiel and its surface area. For various kinds of sensors susceptibility threshold determined by the internal noise. Particular importance have the low–frequency (LF) or flicker noise which power spectral density increases with decreasing of frequency as $1/f^{\gamma}$ law, where γ is the frequency index and has a value of order unity [9-12].

In this paper the influences of properties of the metallic contact sizes and the current flow ways through the semiconductor on the CVC and low-frequency noises in the structures of Cr / n-Si and W / n-Si are investigated.

2. Investigated structures and experimental technique

Two kinds of Schottky barrier samples with structures Cr/n-Si and W/n-Si were prepared. The manufacturing process of the samples is described in [13]. Contacts 1 and 2 were created on the samples with a Schottky barrier and ohmic contact 3 (Fig. 1). In the samples of the first group chromium (Cr) was used as a contact material with the contact area equal to $1.6 \times 2\ \mathrm{mm}^2$ (distance between the contacts 1 and 2 was $l = 3.8$ mm) and in second group of samples wolfram (W) was used as a contact material, with contact areas respectively equal to $1.6 \times 2\ \mathrm{mm}^2$ ($l = 3.8$ mm), $1.8 \times 2\ \mathrm{mm}^2$ ($l = 3.4$ mm) and $2 \times 2\ \mathrm{mm}^2$ ($l = 3.2$ mm).

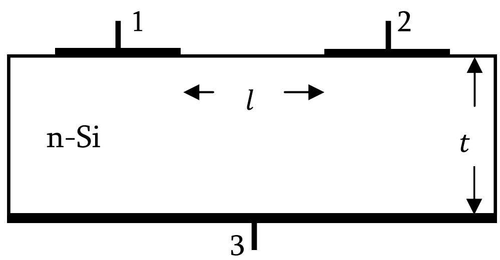

Fig. 1. Structure of the samples and the location of the contacts.

Samples were prepared on n-type silicon wafer with a resistivity of 40 Ω·cm, thickness of Si was 250 μm, the crystallographic direction was <111>.

CVC measured with step of 0.1 V with increasing dependence. Voltage control is carried out by a voltmeter LW-64. Intervals of used voltages are 0 ÷ 4 V. Noises measurement was carried out by direct filtration method in the frequency range from 2 to 500 Hz and temperature T=300 K. Low–frequency noises were measured in constant current mode, i.e. there were measured voltage fluctuations. Values of the current were taken from linear region of sample CVC. Block diagram of the measurement setup is presented in Fig. 2. It consists of current source with low level of intrinsic noises (9 V dc-voltage source) providing dc current through the sample. The total measurement system was placed in a permalloy box shielded from the external electromagnetic influences.

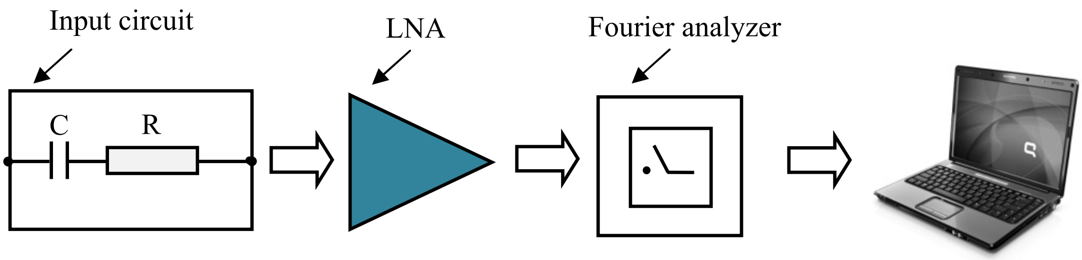

Fig. 2. Noise measurement setup.

The measuring part consists of an amplifier (Model-5184 Preamplifier) and spectral Fourier analyzer (Handyscope 3, TiePieEngineering) operating in Windows 7. Data obtained from spectral analyzer, are transferred to a computer and processed by means of LabView software.

2. Results and discussion

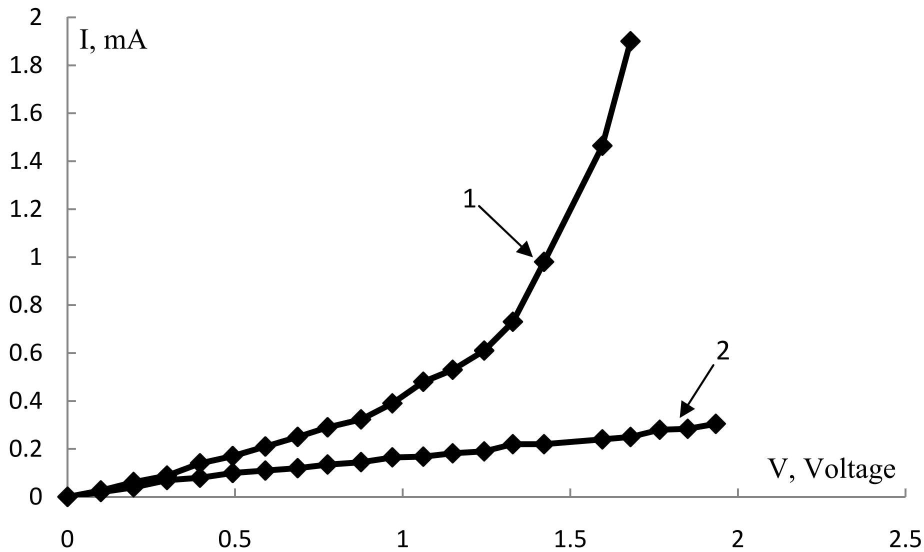

Fig. 3. CVC of Cr/n-Si samples: 1- bulk character of the current, 2- surface character of the current.

Figure 3 shows current-voltages characteristics of samples of the first group with the structure Cr/*n*-Si, when current flows through the volume (between contacts 1 and 3) and through surface of the sample (between contacts 1 and 2). When current flows through the volume with one Schottky barrier at the interface in contact 1–nSi, CVC has an exponential form like a normal Schottky barriers. In current flow case between the surface contacts 1 and 2 forms double oppositely displaced Schottky barriers where current has surface character, and CVC has ohmic views.

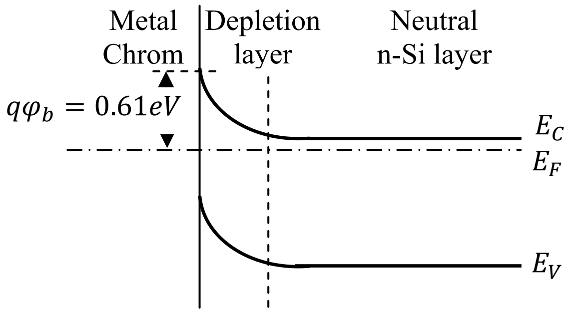

Fig. 4. Energetic band diagram of Cr/n-Si.

Note that the resistance of first group samples was 2.3 ohms between contacts 1 and 3 and 7.5 ohms between contacts 1 and 2. Figure 4 demonstrates energetic band diagram of n-Si contact with the metal (Cr). At the forward bias and applying a positive potential on the external metal electrode, the potential barrier height is reduced, and the current flows through the structure. As part of the generally accepted theory of thermionic emission for rectifying Schottky barrier CVC is described by the relation [1]

$$J = AT^2 \left[exp - \frac{q\varphi_b}{KT}\right]\left[exp\left(-\frac{qV}{nkT}\right) - 1\right],$$

where J is the current density, A is the Richardson constant, T is the absolute temperature, q is the electron charge, φ_b is the barrier height, k is the Boltzmann constant, V is the voltage, n is the diode non-ideality coefficient.

Figure 5 presents the spectra of low-frequency fluctuation noise signal samples Cr/*n*-Si in the flow of volume and surface current. To describe the behavior of the low noise it should be noted that the mechanisms of formation of these noises in semiconductors are mostly reduced to the surface (model McWhorter [14]) and bulk (model based on electron-phonon interactions [15-17]) characters.

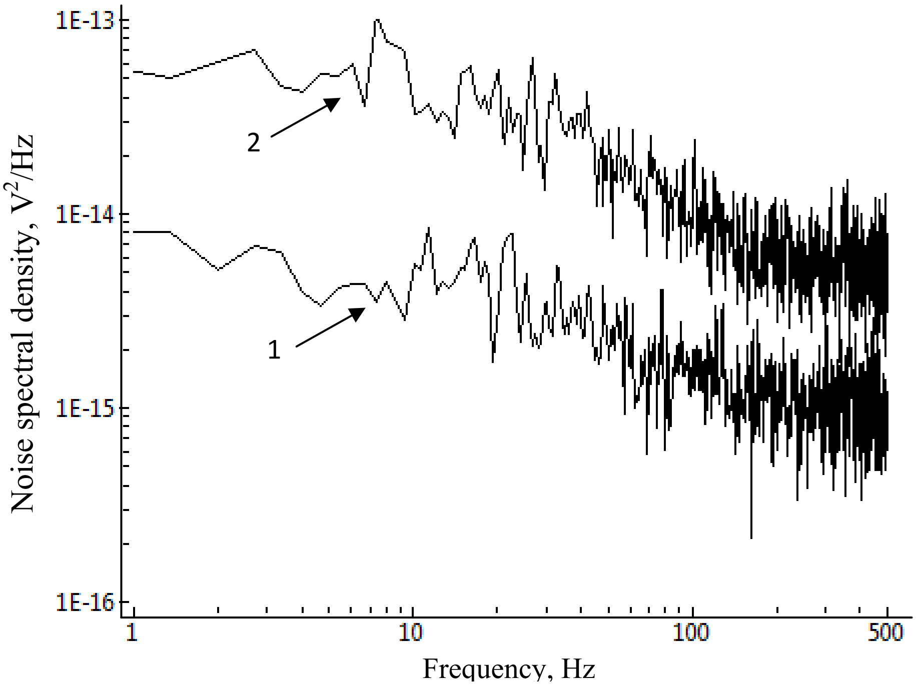

Fig. 5. Noise spectrum for samples Cr/*n*-Si: 1- bulk character of the current, 2- current surface character.

For describing the behavior and for identifying the physical nature of LF noise formation in the case of leakage percolation volume current universal empirical Hooge formula with spectral dependence $S_u \sim 1/f^{\gamma}$ [9] can be used. If current has surface character, as shown in Fig. 5, the spectral density of the noise is higher than when the current flows through the volume of the same sample (the current is 0.2 mA). One of the main mechanisms of formation of the LF noises caused electron-phonon interactions in the volume of semiconductor. Let's note that thickness of the samples are equal to $t = 250$ μm, distance between the contacts is l = 3 mm and bulk current flows smaller distance than the surface current. When current flows between contacts 1 and 2 conduction electrons are captured by surface traps. Current is decreasing. It is clear that the LF noise in this case is mainly due to fluctuations in the number of conduction electrons connected with the capture process on the surface traps [13]. In formation of the noise connected with surface mechanism of course also affects the percolation effect of free electrons through the interface between n-Si with a metal [18]. When current has bulk nature the noise formation is fully explained with the theory proposed in [19, 20] and related to the interaction of electrons with acoustic phonons in the bulk of semiconductor. Both surface and bulk characters of the current LF noise spectrum are well described by the dependence $S_u \sim 1/f^{\gamma}$.

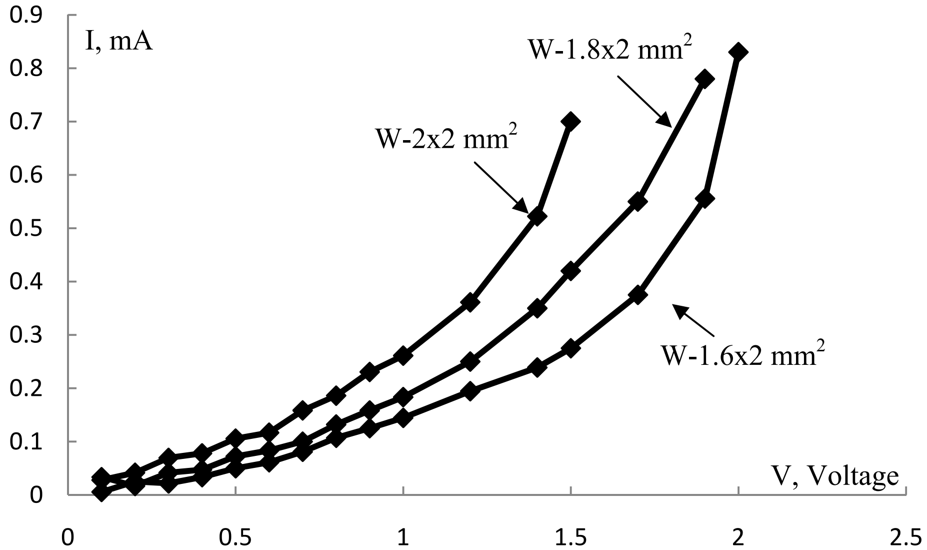

Fig. 6. CVC of the samples W/*n*-Si, when current flows through the bulk of sample between the contacts 1-3.

Figure 6 presents CVC of the samples for the structures of W/n-Si with different contact's area when the current flows through the sample volume between contacts 1-3 (Fig. 1). CVC of the structures W/n-Si are similar to structures Cr/n-Si species and differ only in the values of currents.

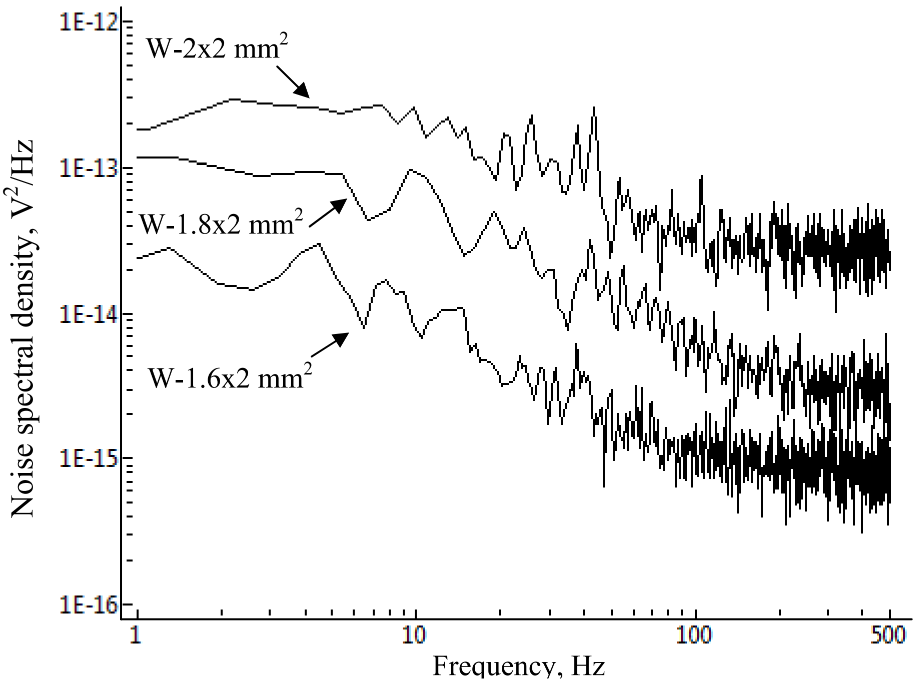

Fig. 7. Noise spectrum for samples W/n-Si, while passing the bulk current between the contacts 1-3.

Current flows through the sample volume, type of CVC is inherent to Schottky barrier. The difference between curves in Fig. 6 caused by the difference of contact's area and resistance of the samples. Because the samples with different surface contacts were not manufactured in the same technological process, they have different resistances which are respectively equal to: $R_{2\times2} \approx$ 3.8 kΩ, $R_{1.8\times2} \approx 5.5$ kΩ, $R_{1.6\times2} \approx 7.6$ kΩ. From a comparison of the data in Fig. 3 and Fig. 6 seems that the current values for the case of W/n-Si are almost half as compared with the case of Cr/n-Si. In addition to the different resistance of the conductive channel, it is also related to the fact that the barrier height for W/n-Si ($\varphi_b = 0.67$ V) is more than for Cr/n-Si ($\varphi_b = 0.61$ V). As seems from Fig. 7 with increase in the contact area, the spectral density of low-frequency noise (noise measured at a current of 0.1 mA) increases too. In this case, the noise behavior can be explained as fully bulk effect [17]. It is assumed that the increase of LF noise is mainly due to the growth of area of the contact metal. When increasing the contact metal area, the number of phonons leaking from the semiconductor into the metal increases, more strongly disturbing thermodynamic quasi-equilibrium in the volume part, the scattering of electrons on the acoustic phonons in the volume of the semiconductor becomes more intense and the noise level increases [18]. The increase in the noise level is also affected by the change in resistance of the samples.

In such a way, it is shown that the noise low level in the metal-semiconductor structures strongly depends on the surface area of metal contacts, and on the type of used metal. Clearly, the choice of the appropriate parameters of the contact material can effectively control the level of LF noise.

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