ISSN 1068–3372, Journal of Contemporary Physics (Armenian Academy of Sciences), 2015, Vol. 50, No. 2, pp. 170–176. © Allerton Press, Inc., 2015.
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Low-Frequency Noises in the Metal–Semiconductor Contact

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Received November 28, 2014

Abstract—CVC and low-frequency noises of metal–semiconductor structures were investigated at the room temperature. CVC and low-frequency noise spectra of the diode structures with the Schottky barrier based on the Fe/*n*-Si, Cr/*n*-Si and W/*n*-Si are obtained. It is shown that the CVC, the noise level and its frequency index are strongly depend on the choice of metal contact and its surface area. The physical processes that influence the level and the behavior of low-frequency noises are revealed. From the standpoint of reducing the level of low-frequency noises it was found that the contact material of chromium is better as compared with the iron or wolfram.

DOI: 10.3103/S1068337215020103

Keywords: low-frequency noise, metal–semiconductor structure, Schottky barrier

1. INTRODUCTION

Schottky diodes are the promising nonlinear elements, which used widely in integrated circuits. In Schottky diodes the metal-semiconductor transitions are used as a Schottky barrier (instead of *p-n* junction in conventional diodes). The Schottky barrier has a lesser electric capacitance, which enables one to increase essentially the operating frequency of diode [1]. Conventional silicon diodes have the forward voltage drop 0.6–0.7 V. The application of Schottky diodes enables one to reduce this drop to 0.2–0.4 V. Such a small forward drop is typical only to the Schottky diodes with the maximal inverse voltage about tens of volts [2, 3].

At present the role of processes, which take place at the interface of semiconductor with the other materials, such as metal, dielectric, electrolyte and gas, is under intensive study. The contribution of these processes in the current flow as well as in other electrical parameters are revealed. It is usually assumed that all these processes are related to the processes taking place in the near-surface layer of semiconductor [3, 4]. Micro- and nanoelectronic devices using these effects are widely known as biochemical and gas sensors [5–12]. A special place in this series has the metal–semiconductor contact. In most cases, metal species is still limited only by choosing the magnitude of the work function. In most cased choice of the type of a metal was limited only by the choice of the quantity of work function [13].

Main trends in the development of modern chips containing the metal–semiconductor contact are related to the decrease in geometrical sizes, reduction of energy consumption and increase in of the signal to noise ratio. Since the useful level of signal sometimes impossible to increase to the desired level without distortions, there is a need to decrease the level of internal noises. One of the methods to solve this problem is the change of area and type of current collector metal contact [14]. It is known that in semiconductors and semiconductor devices the flicker noise prevails at low frequencies, the power spectral density of which is increasing with the decrease of frequency according to the low $1/f^{\gamma}$ [5, 8, 13–17], where γ is frequency index of the order of unity. The noise diagnostics is one of the powerful and sensitive techniques to investigate the properties of semiconductors and devices of various purposes, in particular, for metal–semiconductor structures [14, 15, 17, 18]. To determine the dependence of electrophysical parameters of the metal–semiconductor contact on the properties, type of metal and its geometrical sizes one needs the comprehensive study of the internal noises of the metal–semiconductor structures for different contact metals and various areas of contact metals [14, 17, 18].

This paper presents the features of the influence of contact metal type, its sizes and the paths of current flow (surface or volumetric) on the CVC and low-frequency (LF) noises of the Fe/*n*-Si, Cr/*n*-Si, W/*n*-Si structures.

2. SAMPLES AND EXPERIMENTAL TECHNIQUE

Two types of samples with the Schottky barrier of Fe/*n*-Si, Cr/*n*-Si, W/*n*-Si structures were prepared. In sample *1* the area of contact was equal to 1.6×2 mm^2, and in sample *2* one was equal to 2×2 mm^2. The construction of structures under investigation is presented in Fig. 1. Samples were prepared on the *n*-type silicon wafers with the resistivity 40 Ω cm, the thickness 250 µm and the crystallographic direction <111>. The current collector contacts are manufactured by the ion-plasma sputtering in the vacuum assembly U279 040RMZ. The manufacturing process of samples consisted of three stages. First stage is the argon-ion purifying surface of silicon plates (the beam current is 0.2 A; to obtain the ion beam, the anode-cathode high voltage is 2 kV, the purifying time is 2 min, the pressure is 6×10^{-4} Torr). Second stage is the sputtering of Fe, Cr и W atoms on the surface of silicon plate (the cathode current is 80 A, the anode current is 2–3 A, the anode voltage is 50 V, the pressure in chamber is 6×10^{-4} Torr, the sputtering time is 20–30 min depending on the type of atoms). On this stage, the contacts *1* and *2* with the Schottky barrier were created (see Fig. 1). Third stage is the ion bombardment deposition of aurum atoms with the 1% content of antimony on the back surface of sample to obtain the ohmic contact (contact *3*, Fig. 1). The thickness of metal contacts is 1200±100 Å. The resistance between contacts *1* and *2* is approximately 10–20 kΩ and between contacts *1* and *3* it is approximately 6–8 kΩ depending on the deposited metal. The Schottky barrier *n*-Si/contact *1* and *n*-Si/contact *2* were shifted in the forward and reverse bias, accordingly.

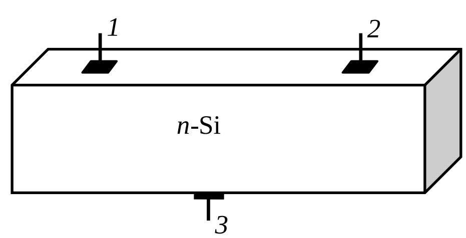

Fig. 1. Structure under study. The sizes of contacts: sample *1* – 1.6×2 mm^2, sample *2* – 2×2 мм^2.

The CVC were measured using 0.1 V step in an ascending order. Voltage monitoring was carried out with use of the LW-64 voltmeter. The range of used voltages was 0–4 V.

The measurements of the LF noise were performed by the direct filtration technique in the frequency range 1–500 Hz and at the temperature T = 300 K. The noise were measured in the regime of direct current, i.e., the fluctuations of voltages were measured. The current values were taken from the linear forward-bias region of the CVC of samples. Noise measurement circuit comprises a power supply with the low noise Panasonic HHR-9SGE, which provides a direct current through the sample, the Preamplifier Model-5184 and the Fourier analyzer Handyscope 3. The Handyscope 3 software was synchronized with the Windows 7. The data of Fourier analyzer were processed with the use of LabVIEW software. The measuring system is encased and insulated from external electromagnetic influences by the permalloy box.

3. RESULTS AND DISCUSSION

Figure 2 shows the CVC of samples *1* and *2* for Fe/*n*-Si structure, when the current passes through the samples volume between the contacts *1–3* (Fig. 1). The CVC of Cr/*n*-Si and W/*n*-Si structures have the similar character and differ only by the values of currents.

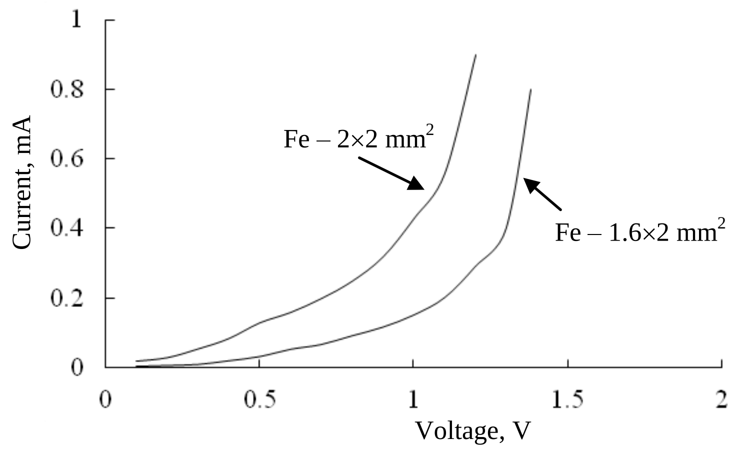

Fig. 2. CVC of samples *1* and *2*, when current flows through the samples volume between the contacts *1* and *3*.

It is seen in Fig. 2 that the CVC of both samples have an exponential form, which is related with the passing of current through the volume of sample and origination of the Schottky barrier. The curves difference in Fig. 2 is caused by the difference of collector contacts areas, as well as by the different resistance of both samples. Since the samples with different areas of contacts were not prepared in the same technological process, the resistances $\left(R_{2\times2} \approx 6.0\,\mathrm{k\Omega},\ R_{1.6\times2} \approx 8.1\,\mathrm{k\Omega}\right)$ for samples with the contacts areas 2×2 mm^2 are lesser that for the samples with the area 1.6×2 mm^2.

The spectra of LF noises of fluctuations signals of samples *1* и *2* by passing of the volumetric current between the contacts *1–3* are shown in Fig. 3. To describe the behavior of LF noises, note that the mechanisms of formation of these noises in semiconductors mainly reduce to the surface ones (the Mc.Whorter model [22]) and volumetrical (the model based on the electron-phonon interaction [15, 16, 18–20]) characters. To describe the behavior and to reveal the physical nature of the LF noises origination

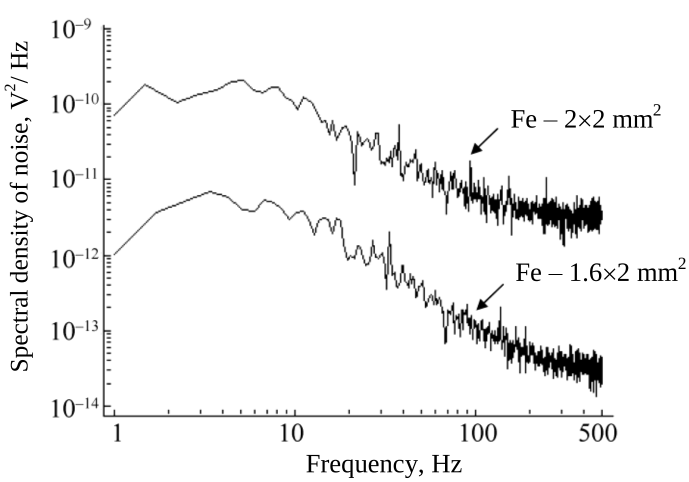

Fig. 3. Noise spectra of signal fluctuations of samples *1* and *2*, when current flows through the volume between the contacts *1* and *3*.

in the case of current passing in the volume, one may use the universal empirical Hoog's formula with the spectral dependence $S_u \sim 1/f^{\gamma}$ [15].

As indicated by Figure 3, when the current is volumetrical, the noise spectral density of sample *2* is higher than for the sample *1*, and the exponent γ of sample *2* ($\gamma \approx 1.2$) is lesser than for the sample *1* ($\gamma \approx 1.7$). This means that the noise level is higher in the case of structures with the contacts with the greater area, and the frequency exponent γ is smaller as compared with the contacts with the smaller area, when the volumetrical current of the same value is passing (the value of current was 0.1 mA). It is supposed that the rise of the LF noise level for samples with greater area of contacts is caused mainly by the increase in the contacts area, since the decrease in applied voltage to conserve the dc should not result in an essential increase in the noise level. Note also that with the increase in contacts area the noise spectrum becomes smooth.

Figure 4 shows the CVC of both samples for Fe/*n*-Si structure, when the current has the surface character (the current is measured between the contacts *1* and *2*, Fig. 1). As would be expected in this case, we deal with the surface current and the CVC has the ohmic character.

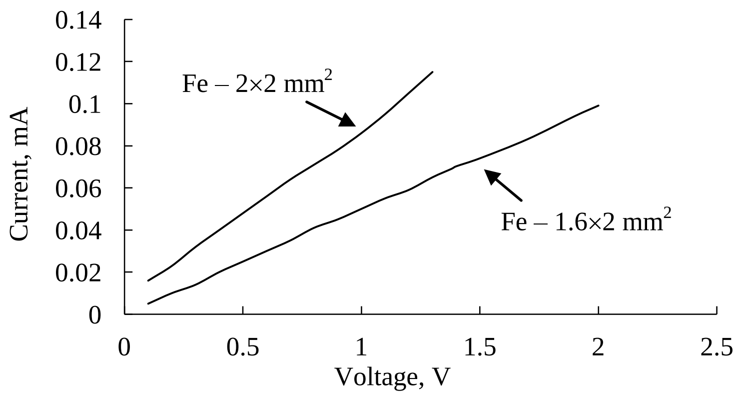

Fig. 4. CVC of samples *1* and *2*, when current flows through the surface of samples between the contacts *1* and *2*.

The spectral density of noises for sample *2* is higher than for the sample *1* and the value of γ for the sample *2* is $\gamma \approx 0.6$, and $\gamma \approx 1.1$ for the sample *1* (Fig. 5). As to volumetrical and surface current

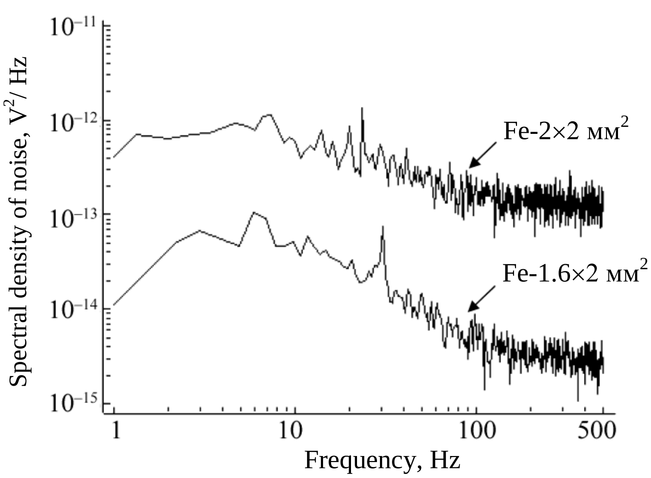

Fig. 5. Noise spectra of signal fluctuations of samples *1* and *2*, when the surface current is passed between the contacts *1* and 2.

characters, the LF noise level increases in dc regime with the increase in the area of current collector contact and the value of frequency index γ is decreasing.

Figure 6 shows the noise spectra of samples with the same areas of contacts 1.6×2 mm^2 (samples *1*), but for different contact materials in the case of current passage through the volume of samples. It is apparent that the spectral density of noise is higher for the sample with the W contact than for the samples with the Fe and Cr ones. The exponent γ of the sample with the W contact ($\gamma \approx 0.7$) is lower than in the cases of Fe ($\gamma \approx 0.9$) and Cr ($\gamma \approx 1.3$).

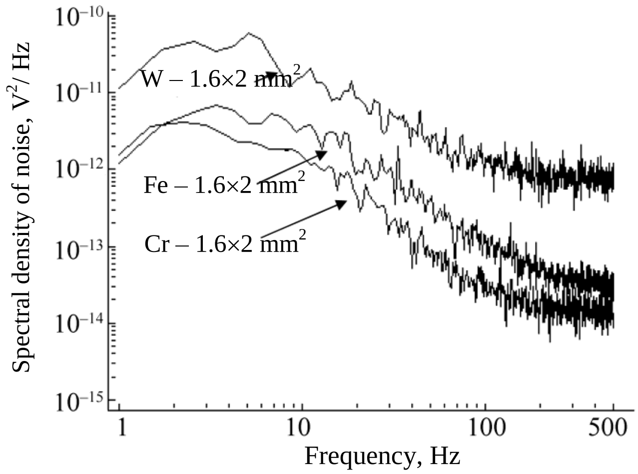

Fig. 6. Noise spectra of signal fluctuations between the contacts *1* and *3* for the W/*n*-Si, Fe/*n*-Si, Cr/*n*-Si structures.

Thus, regardless of the current passage nature (volume or surface), the level of LF noise as well as the exponent γ depend strongly on the value of the area of collector contact and the type of contact materials.

The volumetrical model of LF noise is based on the electron-phonon interaction inside the volume of semiconductor. The scattering of electrons on the lattice oscillations is described with the use of radiation and absorption of phonons by moving electrons [17]. The level of the LF noise depends on the average reflection coefficient of long-wave acoustic phonons (AP) on the interface between the semiconductor and the contact material [14–21].

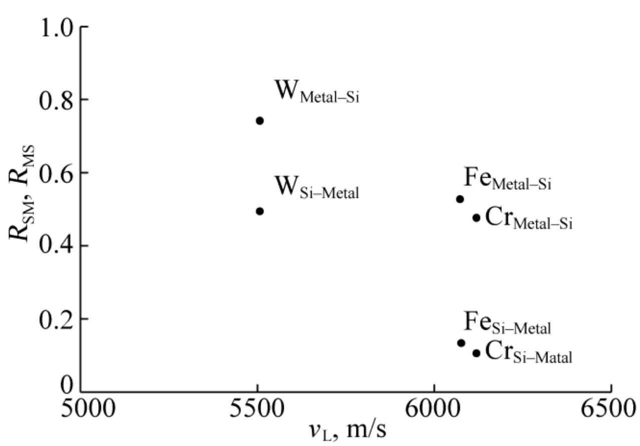

Fig. 7. Percolation coefficients and AP from silicon to metal and vice versa [14]; v_L is the speed of longitudinal phonons.

Figure 7 shows the values of percolation coefficients at the interface in the Fe/*n*-Si, Cr/*n*-Si, W/*n*-Si systems [14], and Fig. 8 represents the scheme of processes of reflection and percolation of AP. Here R_{SS} and R_{MM} are the reflection coefficients of AP and R_{SM} and R_{MS} are the percolation coefficients at the interface between the semiconductor and metal, and v.v. It can be seen in Fig. 7 that the percolation coefficient for AP has the minimal value in the case of the Cr contact material (high reflection coefficient).

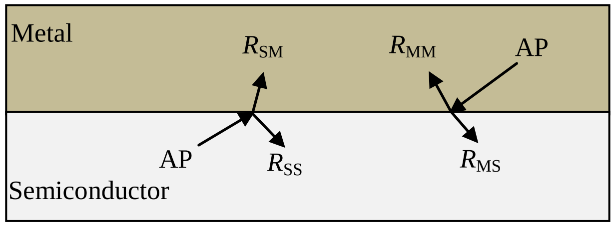

Fig. 8. The diagram illustrating the percolation and reflection of AP at the interface.

Figure 6 demonstrates that the value of noise spectral density in the Cr/*n*-Si structure is lower as compared with the Fe/*n*-Si и W/*n*-Si structures. As shown in [14, 16–21], one of the main mechanism of the LF noises formation is caused by electron-phonon interactions in the volume of semiconductor. The lesser is the coefficient R_{SM} , the greater is the number of remaining longitudinal AP in the semiconductor. As a result, in the semiconductor volume the state of thermodynamic quasi-equilibrium will conserve between the systems of interacting electrons and AP. As is seen in Fig. 7, the noise level in the structure with the chromium contact is minimal. The LF noise dependence on the area of the metal collector contact will be caused mainly by the number of phonons percolating from the semiconductor to metal. With the increase in contact area, the number of phonons percolating from the semiconductor into the metal is increasing and in the volume of the semiconductor the thermodynamic quasi-equilibrium is violating, the scattering of electrons on phonons becomes more intense and the level of LF noise increases. Such an explanation of the behavior of LF noises describes the behavior of the experimental curves in Figs. 4, 6 and 7 within the frames of electron-phonon interaction.

In summary, by choice of contact materials and surface area, one may control the level of LF noise in the devices with the interface between metal and semiconductor.

ACKNOWLEDGMENT

Authors are grateful to S.V. Melkonyan for discussions and useful comments.

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