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Difference in the electric behavior of micro- and nano Schottky diodes

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ABSTRACT

The real Schottky diode (SD) consists of set in parallel connected both electrically cooperating micro- and nano contact ever micro- and nano contacts separately differ from each other only in potential barrier height. They are in an environment of the next micro sites of the general contact surfaces of SD and because of their interaction there is an additional electric field. Under action of an additional electric field character of interrelation of barrier height and the ideality factor of micro-and nano contacts gets specific features. Between the experimental results and energy diagram of the real metal–semiconductor contact has been good agreement.

1. Introduction

Real Schottky diodes (SD) as completing active and passive elements are widely used in modern electronic devices and at the same time their electro physical properties are still intensively investigated. Thus the big attention to specific features current transport, described by potential barrier height and the ideality factor of SD [1–4] is paid. Results of numerous experimental researches show, that between potential barrier height (ϕ_B) and the ideality factor (n) SD does not exist unequivocal correlation [5–12].

In work [5] it is established that with increasing Φ_B in SD, their factor n linearly decreases and is supposed that such dependence is caused by laterally heterogeneity of contact. The same result is received in [6]. The parameters varied from 0.835 to 0.856 eV, and 1.02 to 1.08 [7]. It was found [8] that the values of barrier height in Au/n-GaN obtained from the capacitance–voltage (C–V) characteristics (1.43 eV) and I–V characteristics (0.89 eV) are different from each other by 0.54 eV. In work [9] barrier height in homogeneity and its origin has been investigated for Au and Cu/n-InP contacts. The

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discrepancy between the barrier heights explained in terms of barrier height in homogeneity approach in [10] has fabricated the Sn/*p*-Si SD with different surface treatments. The anodeization, on the other hand, has increased both, the Φ_B as well as the *n* factors. The electrical properties of SiC contacts have been studied in [11] by current-sensing atomic force microscopy (CS-AFM) and X-ray photoelectron spectroscopy (XPS). The obtained results indicate that the Φ_B and n factors of nano SD are different from one nano contact to another. The experimental Φ_B and n factors on three nano contacts were found to be 1,03, 1,10, 1,35 eV and 1,18, 1,20, 1,20, respectively. In the [12] transport properties of two types of electrochemically produced nanometer-sized Ag, Sn, Co, Ni and Pt with GaAs and InP Schottky contacts were investigated. I–V characteristics of single nano-dot contacts directly measured by a conductive AFM probe showed nonlinear I–V character in semi-logarithmic scale.

Thus, in spite of the fact that complex character of dependence between Φ_B and n factor still remains a subject of intensive researches, all works marked that these dependences are consequence of heterogeneity of interface of contact SD. Inhomogeneous SD represents set in parallel connected cooperating (instead of isolated from each other) micro- and nano contact with different local potential barrier heights owing to which arises the additional electric field actively participating in formations of potential barrier height and current transport [3]. Features of an additional electric field depending on diameter of contact and the thickness of metal leading reduction of potential on a free surface of the semiconductor with width of the order of some micrometers around of the contact surface Au/n-GaAs SD are studied by means of AFM microscopy in [13].

In this work result of experimental researches of current transport in Au/n-Si, Au/*n*-GaAs, Au/*p*-Si and Ni/*n*-Si micro- and nano-SD were studied. And relations between Φ_B and n factor and interpretation of the received results with heterogeneity SD with view the additional electric field are presented [14–19].

2. Experimental details

For understanding the one the most important sources of difference in the electrical behavior in micro and nano Schottky diodes, first *n*-type Si with B impurity, crystal orientation of (1 1 1), thickness of 275 ± 15 μm and resistivity of 4–11 Ω cm was selected. For cleaning the RCA method was applied. For better cleaning of samples' surface, we used plasma cleaner with voltage of 1 kV for 20 min under pure Argon ions, this action repeated in all of examples.

In second step high-quality Ni/*n*-Si Schottky diodes with low reverse leakage current are produced using molybdenum mask with sizes 500 and 700 μm and then small high-quality Au/*n*-Si and Au/*p*-Si Schottky diodes with low reverse leakage current are produced using lithography. Their effective barrier heights (BHs) and ideality factors from current–voltage (I–V) characteristics are measured by a Pico Amper meter and home–built I–V instrument. In another work *n*-type GaAs with crystal orientation of (1 0 0), thickness of 400 μm and resistivity of 1 Ohm-cm was selected. For making ohmic contact Ag–In (95–5%) alloys was used. Deposition procedure was done immediately after cleaning in a vacuum chamber at 10^{-5} Torr with plasma arc cleaning method for 20 min. The metal alloy was deposited to 200 nm thick. We made two set of 40 Schottky diodes with width of 1 and 4 μm with help of wet lithography. At least, *n*-type Si single crystal with (1 1 1) orientation, 275 μm thickness and 4–11 Ω cm resistivity is selected. Immediately after surface cleaning, pure aluminum (Al) with thickness of 150 nm was thermally evaporated from the tungsten filament on the whole back surface of the wafer in the pressure of 10^{-5} Torr with an electron beam gun coating system model EMS-160 made by High Vacuum Technology Center (ACECR-Sharif University Branch-Iran). The Schottky contacts were formed on the other faces by evaporating gold (Au) with a thickness of 200 nm in the pressure of 10^{-5} Torr. Metal layer thickness as well as deposition rates were monitored helping of a digital quartz crystal thickness monitor. The deposition rates were 1–4 A^0/s. We made five samples of 5, 10, 20, 50, 100 μm. I–V measurements were performed at room temperature using a commercial homebuilt I–V measuring unit containing a Keithley 4586 with a probe station and $PtIr_5$ 40 nm tip. The topographical pictures were measured in AFM mode with Al coated Si tip with 1 nA tunneling current. For this propose we used DME AC – AFM with cantilever height 160 , width 45 ,thickness 45 nm , force constant 42 N/m, Resonance frequency f = 285 kHz , and Tip curvature radius ⩾ 10 nm made from $PtIr_5$ materials [14–19].