Si Wires for Strain Sensor Application

Anatoly Druzhinin, Igor Ostrovskii, Tomasz Palewski, Stepan Nichkalo, Roman Koretskyy, Yevgen Berezhanskii

Abstract – **Resistance and magnetoresistance of Si microwires were studied in temperature range 4,2-300 K at magnetic fields up to 14 T. Ga-In gates were created to wires and ohmic I-U characteristics were observed in all temperature range. It was found high elastic strain for Si wires, linear thermoresistive characteristics as well as small magnitude of magnetoresistance (of about 5% at 14 T), which was used to design multifunctional sensor of simultaneous measurements of strain and temperature with minimal sensitivity to magnetic field intensity.**

Keywords - ***InGa contacts, magnetoresistance, wires, strain sensors.***

I. INTRODUCTION

Carrier transport in Si, in particular in wires was studied in the work [1]. However, mechanism of carrier transport is not enough investigated at the range of cryogenic temperatures in the wires. Analysis of magnetoresistance character is one of the methods, which allows investigating conductance in the temperature range (4,2¸300) K. There are many works [2, 3] devoted to theoretical and experimental studies of magnetoresistance in Si in the vicinity to metal-insulator transition (MIT). But all studies on measurements of magnetoresistance of Si wires were conducted on crystals of large diameters > 50 μm [4]. Electric properties of Si nanowires are hard to measure due to a problem of ohmic gates fabrication. The convenient method for gate creation is well-known welding of Pt or Au microwire. But the method is not appropriated for nanowires due to their strain because of large gates. So, Ga-In contacts are appropriated for this purpose.

The paper deals with an investigation of Si microwires resistance and magnetoresistance at temperature range 4,2-300 K in order to design strain and temperature sensors on their base.

II. EXPERIMENTAL RESULTS

The wires were grown by chemical vapour deposition method and. The free standing Si wires have diameters ranging from 5 to 20 μm. Electric gate to the crystals were made from Ga-In melt, freezing temperature of which is about 310K. The I-U characteristics were measured in temperature range 4,2-300 K. As have been shown the characteristics were ohmic in temperature range 4,2-300 K.

Anatoly Druzhinin - Lviv Polytechnic National University ,S. Bandery Str., 12, Lviv, 79013, UKRAINE, E-mail: druzh@polynet.lviv.ua

Tomasz Palewski – International laboratory of high magnetic fields and low temperatures, Gajowicka Str., 95, Wroclaw, 53-421, Poland

The crystals for investigations were selected with acceptor-impurity (boron) concentration closed to critical concentration of the metal-insulator transition both from metallic side of the transition. The temperature dependences of wire conductance were measured for all samples in the temperature range (4,2¸300) K. The investigation of temperature dependencies of resistance for the wires of various diameters have shown linear growth of resistivity at temperature range 4,2 – 50 K (see Fig.1).

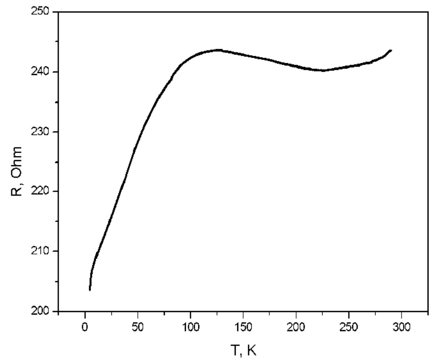

Fig.1 Temperature dependences of Si wire (d=5 μm) resistance (ρ_{300K}=0,01 Ohm·cm)

Wire magnetoresistance was measured at low temperature in the range of magnetic field 0¸14 T. The investigations reveal that magnetoresistance dependences $\Delta R_B/R$ as functions of magnetic field B is linear in wide range of magnetic field intensity and has small value (see Fig.2).

III. DISCUSSION

We have found an exponential field dependence of magnetoresistance for Si wires from metalic side of the MIT. It should be noted that almost linear dependency of magnetoresistance on magnetic field intensity was observed (see Fig.2). Moreover one can underline the very small values of magnetoresistance.

The exponential field dependence of magnetoresistance corresponds to conductance in the Lower Habbard Band with the activation energy ε_3 for insulating samples or to conductance with strong electron correlation in the metallic samples [2].

Effects of electron correlation are likely to occur in metallic Si wires, in which exponential dependences of magnetoresistance are found (Fig. 2). As you can see the magnitude of maximum magnetoresistance at 14 T is very small (of about 5% at 4,2K). The letter value essentially reduces at temperature decrease.

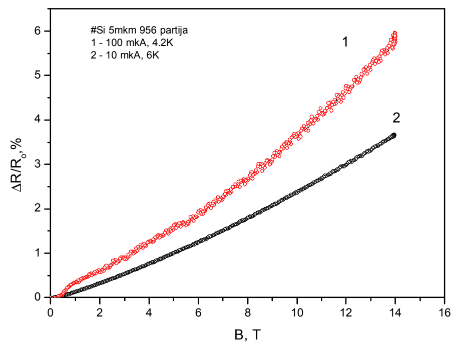

Fig.2. Field dependences of magnetoresistance for Si wire (d=5 μm, ρ_{300K}=0,01 Ohm·cm): 1 – 4,2 K; 2 1– 6 K.

The results are of great importance for sensor application. From one side, we have linear field dependency of magnetoresistance, which can be easily accounted to design of sensor of mechanical values on the base of such wires. From another side, our earlier results show a satisfactory value of gauge factor for such wires (of about 120). A decrease of the wire transverse diameter leads to gauge factor growth (up to 140-150). So, Si wire can be successfully used for design of strain sensors for low temperature range (4,2 – 77 K) (see Fig. 1).

IV. STRAIN SENSOR DESIGN

Sensor for simultaneous measurement of strain and temperature is operating in temperature range 4,2-77 K. Besides the sensor includes a possibility for magnetic field corrections, which is realized due to secondary scheme for signal processing.

The sensor contains two sensitive elements (strained and freestanding), which are situated in bridge scheme. Output characteristics of strained sensitive element is provided in Fig.3. A scheme of signal processing is shown in Fig. 4. A signal from strained sensitive element contains contributions from strain and temperature, while signal from freestanding sensitive element reflects only temperature contribution. A bridge scheme allows us to compensate the temperature contribution and to receive strain signal. A secondary processing scheme enables us to compensate also magnetic contribution at very low temperature due to turning one sensitive element in the direction transverse to magnetic field induction lines.

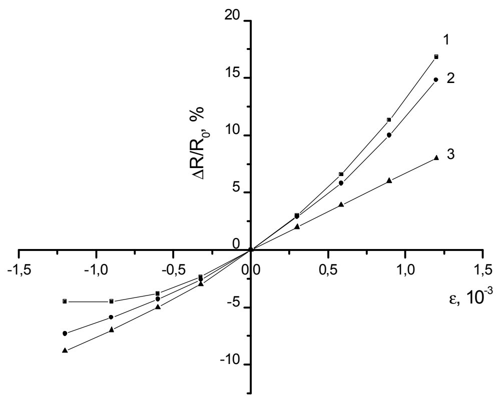

Fig. 3. Strain dependency of relative resistance for p-Si wires with ρ_{300K}=0,01 Ohm×cm: 1 – 4,2 K; 2 – 77 K; 3 – 300 K

The sensor is appointed to measure strain in the range -4×10^{-3} to $+4\times10^{-4}$ a.u. An accuracy of strain measurement is about of 10^{-4} a.u., while temperature accuracy is about 0,3 K.

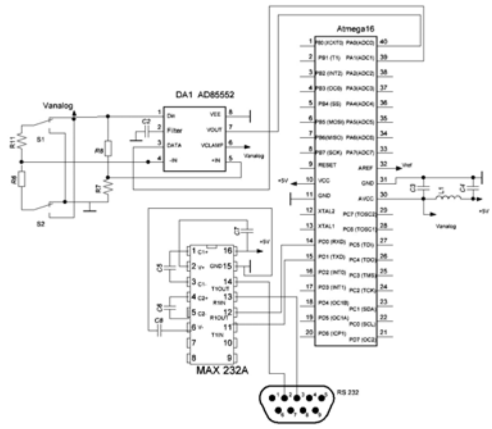

Fig. 4. Scheme of secondary signal processing for strain sensor on Si wire base

V. CONCLUSIONS

The paper deals with investigations of resistance and magnetoresistance of Si microwires (d=5 μm) in temperature range 4,2-300 K at high magnetic field up to 14 T. The study was possible due to a creation of Ga-In gates to microwires, which show ohmic contacts in the investigated range of temperatures. The crystals for investigations were selected with boron impurity concentration closed to critical concentration of the metal-insulator transition from metallic side of the transition.

As a result of studies it was found linear dependence of magnetoresistance on magnetic field intensity for Si wires, that is important for sensor applications. So, high elastic strain for Si wires (gauge factor of about 150) as well as small magnitude of magnetoresistance (of about 5% at 14 T) allow us to design multifunctional sensor for simultaneous measurements of strain and temperature with minimal sensitivity to influence of magnetic field.

REFERENCES

[1] A.Druzhinin, E. Lavitska, I.Maryamova et al. “Studies of Pieoresistance and Piezomagnetoresistance in Si Wires at Cryogenic Temperatures” *Cryst.Res. Technol*. 2002, vol.37., pp.243-257.

[2] E.El. Rafey, S.A. El.-Atawy. “Magnetoresistance of intermediate concentration n-Ge at helium temperature” *Can. J. Phys*., 1987, vol.65., pp.88.

[3] T.G.Gastner, W.N.Shafarman, J.S.Brooks, K.P. “Martin The metal-insulator transiton in n-type Si in high magnetic fields”*Solid State Phys*, 1988, N5, pp.366.

[4] A.A.Druzhinin, I.V.Pavlovskyy “Strain dependency of magnetoresistance of Si wires in the field of metal-insulator transition” *Abstract of V Interm. Conf. on Actual problems of semiconductor physics*, Drobybych: “Kamenjar”, 2005., pp. 216-217.