Strain-induced spliting in valence band of Si-Ge whiskers

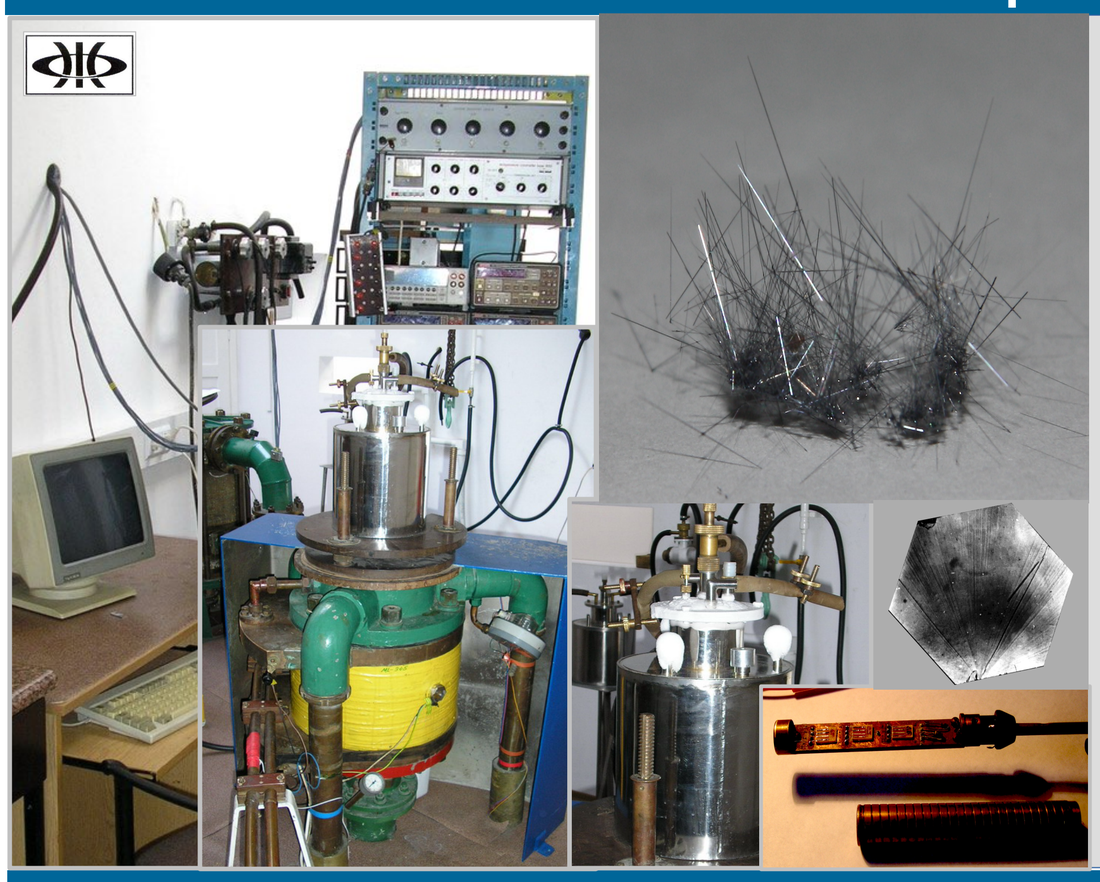
A.Druzhinin, I.Ostrovskii, Yu.Khoverko, N.Liakh-Kaguy, V.Mazur
Department of Semiconductor Electronics, Institute of Telecommunications, Radioelectronics and Electronic Engineering,
Lviv Polytechnic National University, Kotliarevskyi Str., 1, Lviv-79013, Ukraine.
E-mail: Mazurlera68@gmail.com

Introduction

Nanostructures based on Ge are of great interest due to surprising physical effect such as SdH oscillations [1]. The good perturbation tool is strain. Due to application of strain to Ge sample the six-fold degenerated valence band the splits on three sub-bands corresponding to light and heavy holes as well as sub-band of SO splitting, which is enough large and consists of 0.29 eV. Light and heavy hole sub-bands in turns splits due to spin-orbit coupling (SOC) under strain in k≠0 direction. Ge whiskers have been investigated under strain action showing magnetophonon oscillations and giving the values of effective mass of heavy and light holes [2]. However, SOC in the whiskers have not been studied.

Therefore, the purpose of the paper is to study the splitting of valence band of doped silicon-germanium whiskers with concentration in the vicinity to MIT under compressive strain to determine the conduction mechanism at low temperatures.

Experimental Procedure



The p-type silicon-germanium whiskers were chosen as the object of investigation with boron concentration correspondent of 1×10^{18} cm^{-3}. Electrical contacts were established by pulse welding using, which provides the necessary ohmic contacts. Conductivity was studied at temperature 4.2 K. For these studies crystals were cooled to liquid helium temperature in the helium cryostat. The temperature was measured by using the thermocouple Cu-CuFe calibrated with use of CERNOX sensor.

The magnetic field effects of the whiskers was studied using the Bitter magnet with the induction to 14 T and the time scanning of field 1.75 T/min. Stabilized electric current along the whisker was created by the current source Keithley 224 in the range 1–100 μA depending on the crystal resistance. CERNOX sensor was used for magnetic measurement, in particular for its thermostabilization. It is weakly sensitive to magnetic field induction. The change of its output signal in the field with induction B=15 T consists of about 1%.

Experimental Results

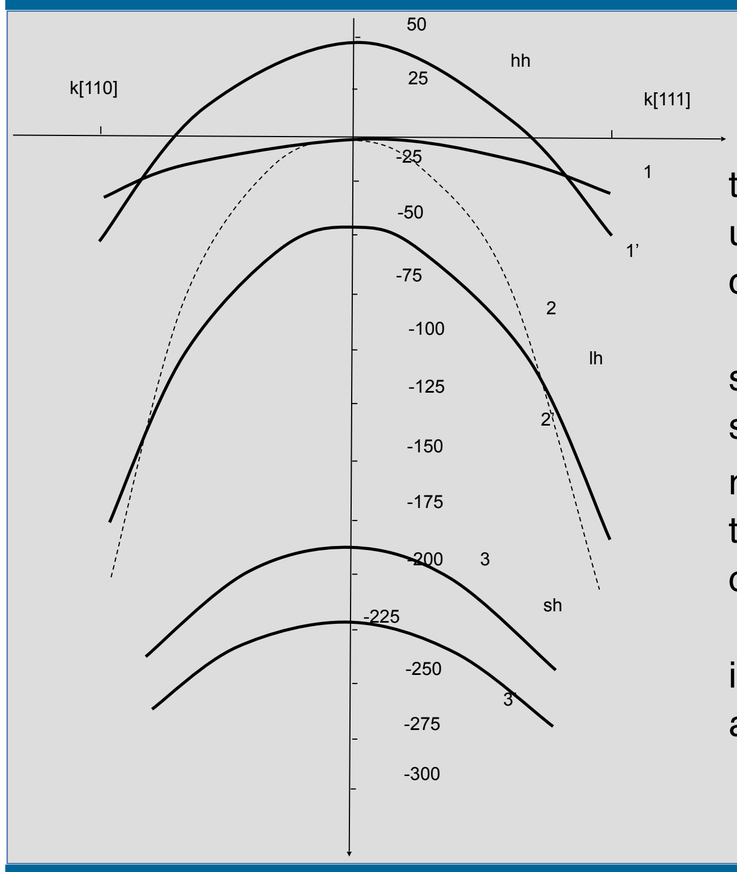
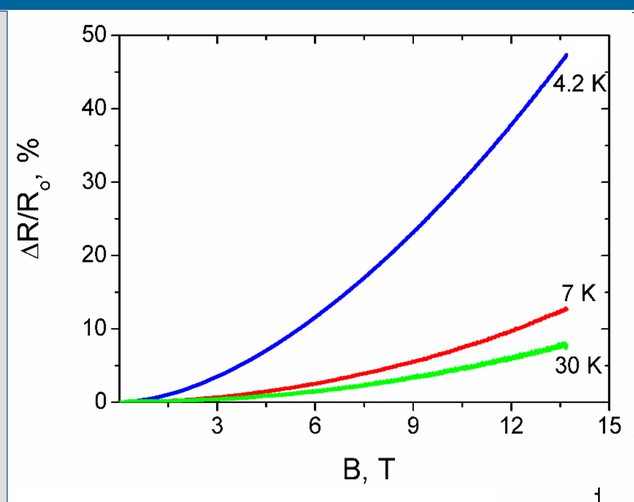


Figure shows the energy spectrum of the valence band of SiGe under the uniaxial compressive strain along the crystallographic direction [111].

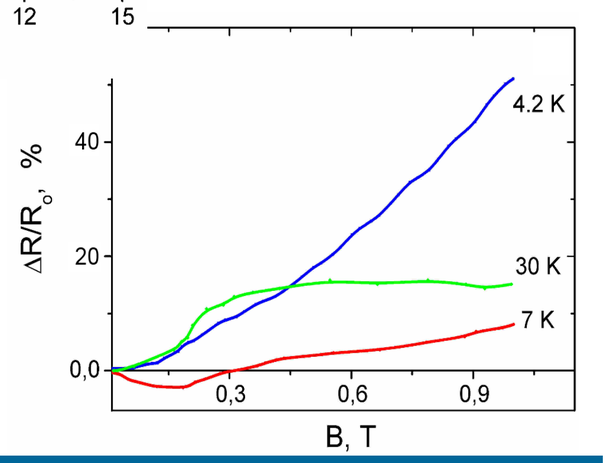
To account for the spin-orbit-deflated so-zone ($l = 3$) having the representation symmetry Γ_{8+}, we accept the known nonlinear strain of the approximation of the energy spectrum in the vicinity $\mathbf{k} \approx 0$ obtained by the invariant method.

In SiGe, the influence of the so-zone is felt only with significant compressive and tensile strain $|\varepsilon| > 0.6\%$



Magnetoresistance non-strained Si_xGe_{1-x} of whiskers with ρ_{300K} = 0,018 Ohm×cm at different temperature

Magnetoresistance strained Si_xGe_{1-x} of whiskers with ρ_{300K} = 0,018 Ohm×cm at different temperature



Conclusion

The longitudinal magnetoresistance of the p-type silicon-germanium whiskers with boron concentration of 1×10^{18}cm^{-3} was measured in the range 0–14 T at temperatures 4.2–70 K under the compressive strain up to -3×10^{-3} rel.un. The strain influence on the degenerate energy spectrum of heavy and light holes by the method of perturbation theory is described, summing up the well-known consideration to arbitrary strains and highlighting the geometric aspects of the theory.

According with two-zone approximation of the k_p-method, the strain removal twice degenerate level Γ_{8+} that leads to the splitting of light and heavy hole branches. From the whisker magnetoresistance the effective mass of heavy holes $m_c = 0.2m_o$ was calculated that is correspondent to decreased value due to the compressive strain. The spin splitting energy for heavy holes Δ_{HH} = 1.6 meV was also obtained and discussed.

1. *H Morrison C., Foronda J., Wiśniewski P., Rhead S.D., Leadley D.R., Myronov M.* Evidence of strong spin–orbit interaction in strained epitaxial germanium // Thin Solid Films.- 2016.- 602.- P. 84.
2. *Druzhinin A.A., Ostrovskii I.P., Khoverko Yu.N., Liakh-Kaguy N.S., Vuytsyk A.M.* Low temperature characteristics of germanium whiskers // Functional Materials.- 2014.- 21(2).- P. 130.