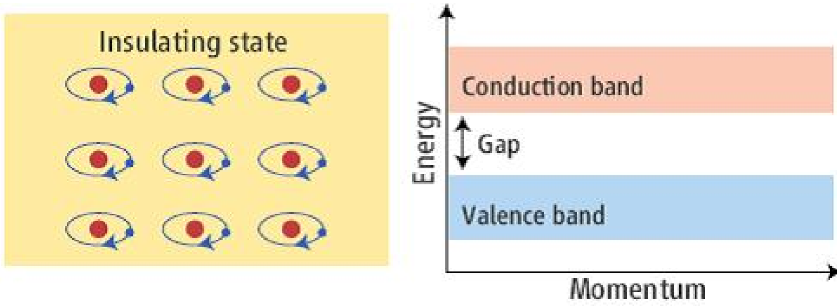
Certain insulators have exotic metallic states on their surfaces. These states are formed by topological effects that also render the electrons travelling on such surfaces insensitive to scattering by impurities. Such topological insulators may provide new routes to generating novel phases and particles, possibly finding uses in technological applications in spintronics and quantum computing.

According to the band theory materials are divided into three groups with respect to their electric properties. The quantity describing the properties is the energy gap between valence and conduction bands. The gap for insulators is ΔE >3 eV, for semiconductors 0<ΔE<3eV and for conductors ΔE=0 eV.

Insulators are divided into several groups with respect to a physical phenomemnon responsible for the insulating state: Mott's insulators, Andresons insulators and "quantum" insulators related to the quantum spin Hall effect. A vivid model of an insulator is presented in Fig.1.

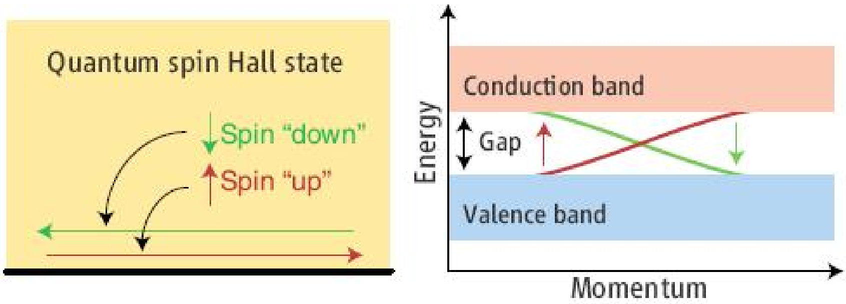


Rys.1. A band model of an insulator. Electrons in an insulator are bound in localized orbitals (left) and have an energy gap (right) separating the occupied valence band from the empty conduction band (Science 314, 1692 (2006)).

To transfer an electron from the valence band to the conduction band one have to deliver energy to the system e.g. thermal energy. Electron transport in quantum insulators is possible if the insulator is subjected to high magnetic field, creating Landau levels (LL). Energy of the levels is quantized. Electrons move in circular paths with the radius of the circle depending on the applied magnetic field.

Near the edges of the material, the electron orbits get interrupted by the surface, and the electron will tend to get bounced back into the material, reversing its velocity. Electrons moving in one direction create so called edge states. The task of the magnetic field is to ensure the time-reversal symmetry i.e. if one reverse the direction of time and also reverse the direction of the magnetic field, everything looks the same.

In topological insulators one can distinguish two types of edge states related to the electron spin up-down configuration – Fig.2. The states are observed without an external magnetic field because the time-reversal symmetry is protected by the coupling.

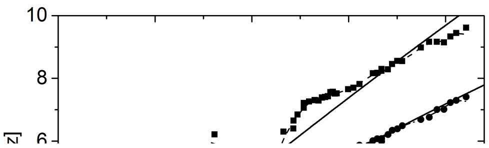


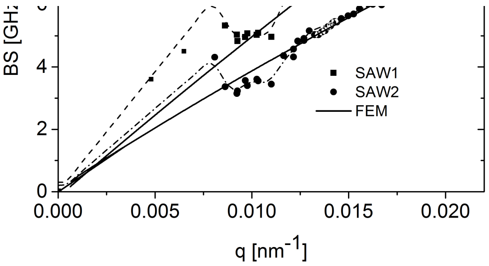
Rys. 2. A band model of the quantum insulator. (Science 314, 1692 (2006)).

Electron transport in a topological insulator is unique due to the fact that it is insensitive to defects, unless the defects show magnetic properties. Are there any other factors affecting the transport?

The topological insulator examined in our laboratory shows excellent thermoelectric properties. Heat transport in solid state is govern by acoustic phonons. Can these phonons affect the electron transport in the insulator? In other word can be the electron-acoustic phonon coupling observed in out topological insulator? Theoretically the coupling was predicted by P. Thalmeira (Phys. Rev. B 83, 125314, 2011) and we are going to verify his hypothesis in our project.

Edge states in the topological insulator are related with its surface. Therefore the coupling can be reflected in a dispersion relation ω(q) of surface acoustic phonons (ω(q) - a dependence of energy of a phonon on its wave vector). The dependence can be measured with a high-resolution Brillouin light scattering spectrometer. According to the theory of elastic properties of solids for small q-values the ω(q) dependence should be linear (solid line in Fig.3. obtained from the Finite Element Method simulations). We measured the dispersion relation for two surface modes – SAW1 and SAW2. From our preliminary measurements it is evident that due to the electron-acoustic phonon coupling experimental results (dots) diverge from theoretical predictions (FEM).





Rys. 3. The disperssion relations for two surface phonons measured in the topological insulator Bi2Te3.
BS – a phonon frequency, q – phonon’s wave vector)

It is well known fact that a heavy nanostructure placed on top of a surface of a solid material modifies its elastic properties creating a phonon band gap. This means that phonons of selected energy are not allowed to propagate on the surface. Such systems are called phononic materials. The second aim of our project is an investigation of the electron-phonon coupling in the surface of the topological insulator decorated with a periodic nanostructure. Selected period and mass of the nanostructure on the surface of the insulator results in the phonon band gap. Within the range of energies of the band gap the coupling should not be observed. Moreover, metallic nanostructure made of a noble metal (Au or Ag) allows for observation of plasmons, i.e. collective excitations of electrons on the insulator’s surface.