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Section

TOPOLOGICAL INSULATORS

abstracts online

FLUCTUATION EFFECTS AND ELECTRON-HOLE PAIRING IN THIN FILM OF TOPOLOGICAL INSULATOR

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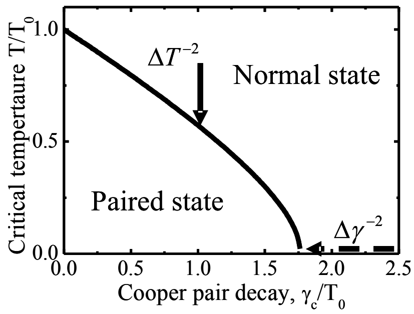
We consider the system of electrons and holes that populate independently gated opposite surfaces of topological insulator thin film. Coulomb interaction can cause electron-hole pairing [1] that leads to superfluidity, anomalies in transport and pronounced internal Josephson effect [2].

We considered influence of Coulomb interaction on tunnel conductivity between opposite surfaces of the film in normal state. Phase diagram of the system in presence pairbreaking with rate γ_c caused by disorder is depicted on Fig.



In absence of Coulomb interaction dependence of tunnel conductivity on external voltage is peak which width and height depend on quasiparticle decay rate and temperature. Coulomb interaction leads to considerable enhancement of tunneling. In vicinity of classical phase transition (solid arrow on Fig) dependence of peak height on temperature is critical one with critical index $\nu = 2$. In vicinity of quantum critical point (dashed arrow on Fig) dependence of tunneling conductivity on Cooper pair decay is also critical one with the same critical index $\mu = 2$. Described above effect can be interpreted as manifestation of Cooper pair fluctuation in normal state.

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[1] Yu.E. Lozovik, V.I. Yudson, *Feasibility of superfluidity of paired spatially separated electrons and holes; a new superconductivity mechanism.* JETP Lett., **22**, 556-559 (1975).

[2] I. B. Spielman, J. P. Eisenstein, L. N. Pfeiffer, and K.W.West *Resonantly enhanced tunneling in a double layer quantum Hall ferromagnet*. Phys. Rev. Lett., **84**, 5808- 5812 (2000).

COLLECTIVE PROPERTIES AND PHASES OF DIRAC ELECTRONS IN TOPOLOGICAL INSULATORS AND GRAPHENE

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Topological insulators is the new state of matter that was recently became to sudy both theoretically and experimentally. 3D topological insulators have insulating bulk and topologically protected helical states on the surface that can be described by Dirac-like equation for massless particles analogously to electrons in graphene. Similarity and distinctions between chiral Dirac electrons in graphene and on the surface of topological insulator will be discussed. Collective excitations and different phases in Dirac electrons in topological insulator, graphene and graphene based structures are considered.

Properties of new quasiparticles, dyons - coupled electrons and magnetic monopole–like polarization originated from magnetoelectric effect in topological insulators will be discussed.

ANDREEV BOUND-STATES OF VORTICES AND SURFACES IN TOPOLOGICAL SUPERCONDUCTORS

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Since the discovery of a superconductor $Cu_xBi_2Se_3$, several works have discussed a possibility if $Cu_xBi_2Se_3$ is really a topological superconductor or not. A key issue to identify the non-trivial topology is Andreev bound-state, which comes from unconventional pairing symmetry and Majorana fermions. The presence leads to distinct observables, e.g., zero bias conductance peak (ZBCP). Recently, Sasaki et al. measured ZBCP's in $Cu_xBi_2Se_3$ and compared them with calculation results considering all possible superconducting pairing symmetries to confirm if Majorana fermions really contribute to create the ZBCP's [1]. However, the study proved that ZBCPs data is insufficient to exclude other non Majorana possibilities. Therefore, more clear and significant evidence of topological superconductivity is now in great demand.

In this talk, we concentrate on the Andreev bound-states in topological superconductors with aid of large-scale parallel solver for Bogoliubov de-Gennes equations [2]. The target system is mainly two-dimensional and we will touch on the threedimensional system with both vortex and surface in the multi-orbital tight-binding model for $Cu_xBi_2Se_3$. Comparing with the past result of chiral p-wave superconductivity [3], we clarify what is a clue to elucidate the topological superconductor $Cu_xBi_2Se_3$.

References

[1] S. Sasaki, M. Kriener, K. Segawa, K. Yada, Y. Tanaka, M. Sato and Y. Ando, *Topological Superconductivity in $Cu_xBi_2Se_3$* Phys. Rev. Lett. 107, 217001 (2011).

[2] Y. Nagai, Y. Ota and M. Machida, *Efficient Numerical Self-Consistent Mean-Field Approach for Fermionic Many-Body Systems by Polynomial Expansion on Spectral Density* J. Phys. Soc. Jpn. 81 024710 (2012).

[3] M. Takigawa, M. Ichioka, and K. Machida, *Vortex structure in chiral p-wave superconductors* Phys. Rev. B 65, 014508 (2001).

ELECTRON-HOLE COOPER PAIRING IN TOPOLOGICAL INSULATOR THIN FILM

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Theoretical and experimental research of topological insulators increasingly grows in recent years [1]. Strong three-dimensional topological insulators have topologically protected surface electron states, described by Dirac equation for massless particles (similar to that in graphene).

Recent advances in growing arbitrarily thin films of topological insulators (such as Bi_2Se_3) [2] suggest to use surface electron states on opposite surfaces of these films as bilayer electron or electron-hole systems. We consider Cooper pairing of Dirac electrons and holes in antisymmetrically doped topological insulator thin films.

Exotic properties of superfluid condensate and vortices in such system were noticed [3], but quantitative estimates of the critical temperature of the pairing in realistic conditions have not been yet presented. We perform these estimations, going beyond simple BCS model. We take into account appearance of the gap due to hybridization of electron states on opposite surfaces of thin films and influence of this gap on the pairing. We also consider self-consistent suppression of the screening of electron-hole Coulomb interaction due to appearance of the gap.

The work was supported by RFBR, by the grant of the President of Russian Federation MK-5288.2011.2 and by the Dynasty foundation.

References

[1] X.-L. Qi and S.-C. Zhang *Topological insulators and superconductors*. Rev. Mod. Phys., **83**, 1057-1110 (2011).

[2] Y. Zhang, K. He, C.-Z. Chang et al. *Crossover of three-dimensional topological insulator of Bi_2Se_3 to the two-dimensional limit.* Nature Phys., **6**, 584-588 (2010).

[3] B. Seradjeh, J.E. Moore and M. Franz *Exciton condensation and charge fractionalization in a topological insulator film.* Phys. Rev. Lett., **103**, 066402 (2009).

BISMUTH CHALCOGENIDE TOPOLOGICAL INSULATORS: FIRST-PRINCIPLES COMPUTATIONAL EXPLORATION

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Topological insulators are the recently discovered electronic materials that have a bulk electronic band gap, but also exhibit metallic surface states as a consequence of the non-trivial topology of the bulk electronic wavefunctions induced by strong spin-orbit interactions [1,2]. These metallic surface states are characterized by the helical spin textures and the absence of spin degeneracy which makes them immune to backscattering and promises novel technological applications. In my talk, I will cover our work aiming towards the understanding of basic electronic properties of bismuth chalcogenides Bi_2Se_3 and Bi_2Te_3, the reference topological insulators discovered in 2009 [3,4], by means of density functional theory first-principles calculations. In particular, I will focus on band dispersion and spin textures of the topologically protected surface states in these materials [5]. Exceptionally strong spin-orbit interaction in these materials entangles the electronic states across broad energy ranges thus reducing the spin-polarization of the topologically protected surface states to ~50%. The helical character of the surface-state charge carriers can be utilized for controlling the magnitude of spin polarization associated with a charge current in thin films of topological insulators by means of an external electric field. Then, I will cover our recent investigation of Bi_2Se_3 and Bi_2Te_3 using the highly accurate first-principles many-body perturbation theory based on the *GW* approximation [6]. The quasiparticle self-energy corrections introduce significant changes to the bulk band structures, surprisingly leading to a decrease in the direct band gaps in the band-inversion regime as opposed to the usual situation without band inversion. The introduction of self-energy corrections in slab-model calculations results in significant shifts of the surface-state Dirac point energies relative to the bulk bands and in enlarged gap openings from the interactions between the surface states across the thin slab, both in agreement with experimental data. In the last part of my talk I will present our recent results aiming towards the understanding surface-state Dirac fermions in the nanostructures of bismuth chalcogenide topological insulators. References

[1] M. Z. Hasan and C. L. Kane, Rev. Mod. Phys. **82**, 3045 (2010).
[2] X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. **83**, 1057 (2011).
[3] Y. Xia *et al.*, Nature Phys. **5**, 398 (2009).
[4] H. Zhang *et al.*, Nature Phys. **5**, 438 (2009).
[5] O.V. Yazyev, J.E. Moore, and S.G. Louie, Phys.Rev.Lett. **105**, 266806 (2010).
[6] O. V. Yazyev, E. Kioupakis, J. E. Moore, and S. G. Louie, arXiv:1108.2088.