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Coalescence of Andreev bound states on the surface of a chiral topological semimetal

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Recently, chiral topological semimetals have been predicted [1, 2] as natural generalization of Weyl semimetals. They are characterized by simultaneously broken mirror and inversion symmetries and non-zero Chern numbers. In topological semimetals, the nontrivial topology results in extensive Fermi arcs connecting projections of bulk excitations on the side surface. In a chiral topological semimetal there is only one pair of chiral nodes of opposite Chern numbers with large separation in momentum space. This leads to extremely long surface Fermi arcs [3], in sharp contrast to Weyl semimetals, which have multiple pairs of Weyl nodes with small separation.

Chiral topological semimetals can be realized, in particular, in a family of transition metal silicides with a chiral crystal structure, including CoSi, RhSi, RhGe, and CoGe single crystals, where CoSi is the mostly investigated material.

In proximity to a superconductor, topological materials exhibit non- trivial physics that can in various cases result in topological superconductivity and existence of Majorana modes. A proximity-induced superconductivity in chiral topological semimetals with multifold fermions, such as CoSi, has been studied until now neither experimentally nor theoretically. Although, a superconducting state allow the existence of topological superconductivity with surface Majorana fermions [4] in a doped chiral semimetal interfaced with the undoped one.

Here, we investigate the magnetic field dependence of Andreev transport through a region of proximity-induced superconductivity in CoSi chiral topological semimetal. We observe sharp subgap peaks, which are usually ascribed to Andreev bound state (ABS) positions. Evolution of these peaks depends on the magnetic field orientation: they are moving together to nearly-zero bias position for parallel to the CoSi flake surface magnetic fields, while there is only monotonic peaks suppression in normal magnetic fields. Also, zero-bias dV/dI resistance value is perfectly stable in parallel magnetic field. These effects are qualitatively similar for In and Nb superconducting leads, so they reflect properties of a proximized CoSi surface.

The behavior of the peaks with increasing in-plane magnetic field can be interpreted as ABSs coalescence due to the joined effect of spin-orbit coupling (SOC) and Zeeman interaction. The effect is known for proximized semiconductor nanowires [5]. The observed magnetic field anisotropy can be associated with the Zeeman interaction of the Fermi arcs states on (001) surface in CoSi, which have recently been predicted to be in-plane spin polarized [6].

Observation of well defined superconducting gap is a direct confirmation of Andreev regime [7] of transport for both type junctions. In the Andreev regime, different subgap $dV/dI(V)$ features are known for finite-size junctions [8]. The pronounced wide central structure in dV/dI reflects the proximity-induced gap, e.g. in the topological surface state [9]. Shallow oscillations originate from Tomasch and MacMillan–Rowell geometrical resonances or multiple Andreev reflection. In contrast, sharp subgap peaks are usually associated with Andreev bound states [8]. It is important, that these features (superconducting gap, oscillations, ABSs) can appear either as dI/dV conductance peaks or dV/dI resistance peaks, depending on the experimental configuration [9].

Our main experimental result is the difference in the ABS evolution for two different orientations of magnetic field, as it is demonstrated in Fig. 1. We trace dV/dI resistance peaks as the ABS positions, following [8] due to the similar experimental setup.

If the field is oriented normally to the flake's plane, no special traces can be observed for ABS resonances, as it is shown by colormap in Fig. 1a and by the $dV/dI(I = 0)$ magnetic field scan in Fig. 1b. This behavior is usual for the superconductivity suppression in magnetic field [7].

In contrast, the zero-bias value $dV/dI(I = 0)$ is stable in parallel magnetic field, while the width of the central region is gradually decreasing. Subgap ABS peaks

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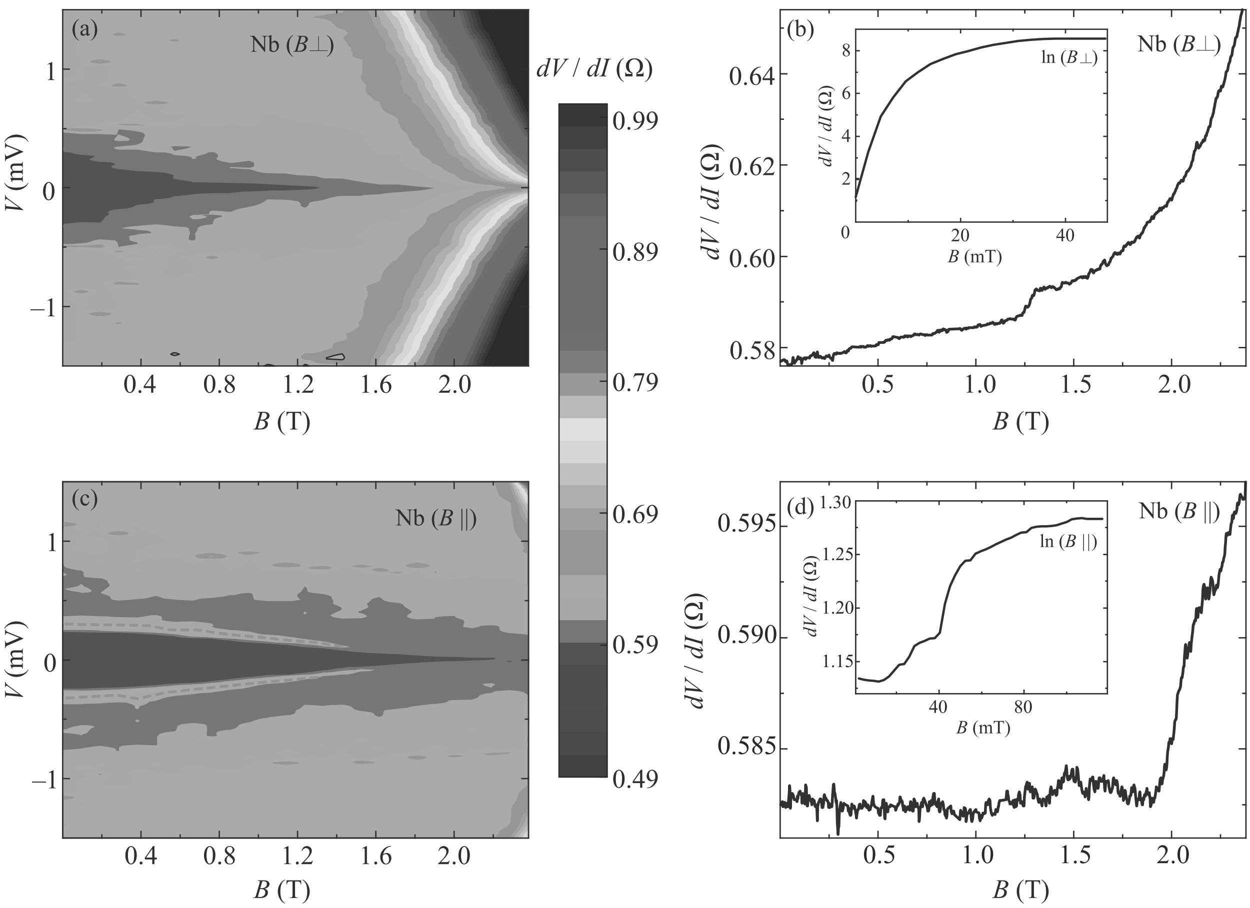

Fig. 1. (Color online) (a) – Detailed evolution of $dV/dI(V)$ level in normal magnetic field for Nb-CoSi-Nb junction. No special traces can be observed for ABS. (b) – $dV/dI(I = 0)$ level is monotonicly increasing in normal magnetic field scan for the Nb-CoSi-Nb junction (main field) and for the In-CoSi-In one (inset). (c) – Subgap ABS peaks monotonicly come to nearly-zero position in parallel magnetic field, they are coalescing together at approximately 2 T, as depicted by yellow dashed lines. (d) – Zero-bias level $dV/dI(I = 0)$ is stable in parallel magnetic field below 2 T for the Nb-CoSi-Nb junction (main field) and below 40 mT for the In-CoSi-In one (inset)

monotonicly come to nearly-zero position, they are coalescing together at approximately 2 T, see Fig. 1c. The stability of the zero-bias level $dV/dI(I = 0)$ below 2 T is also demonstrated by the $dV/dI(I = 0)$ magnetic field scan in Fig. 1d for parallel magnetic field.

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