Pairing symmetry in the topological superconductor candidate $Sr_xBi_2Se_3$-an abnormal phonon broadening in Bi_2Se_3 and $Sr_{0.1}Bi_2Se_3$

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1. Introduction

The discovery of Topological insulators has stimulated the search for their superconducting analogues, topological superconductors (TSs), where the bulk are fully gapped (in the superconducting state) while the surface possesses protected gapless states. By intercalating a typical TI, Bi_2Se_3 with Cu, Sr or Nb atoms, superconductivity can be achieved, which has later been considered as a promising candidate for TS. Point-contact spectroscopy data showing a zero-bias conductance peak coexisting with a superconducting gap of 0.7 meV signified possible unconventional superconductivity in this system. However, scanning tunneling microscopy results on $Cu_{0.2}Bi_2Se_3$ drew a markedly different conclusion. In this work, a superconducting gap without any in-gap states was observed, which can be interpreted as a classic s-wave gap and thus arguing against the previous conclusion of unconventional superconductivity in this system.

A recent proposal from Wan and Savrasov provides one interesting way to examine the superconducting pairing symmetry by measuring the phonons. They performed first-principle calculations and showed that the superconductivity in $Cu_xBi_2Se_3$ was still mediated by phonons. They predicted that both the acoustic and optic phonon modes close to the zone center would exhibit significant broadening that caused the anisotropy mentioned above.

If Wan's calculations were proven true, it has two important implications: 1), $(Cu/Sr)_xBi_2Se_3$ is not a TS, since a TS requires a fully gapped bulk state without any nodes, while in the predictions, there was a nodal plane at kz = 0 ; 2), $(Cu/Sr)_xBi_2Se_3$ will be the first phonon-mediated non-s-wave superconductors. If this is the case, it may open up a new direction for finding unconventional superconductivity. By investigation phonon linewidth using neutron scattering, we are able to answer the question.

2. Experiment

The inelastic neutron scattering measurements on Bi_2Se_3 and $Sr_{0.1}Bi_2Se_3$ were performed on time-of-flight spectrometer AMATERAS, where a multiple-Ei mode with main Ei=10.5 meV and resolution ~ 0.1 meV is used. Both samples were mounted with c axis along the beam direction with a axis in the horizontal plane. The rotation axis is perpendicular to ac plane, and scan step is narrowed to 0.5 degree around Bragg peak (0 0 -15) and (1 0 -5) for better data quality. The temperature is 17 K and lattice parameters are a=b=4.14 angstrom and c=28.6 angstrom for both Bi_2Se_3 and $Sr_{0.1}Bi_2Se_3$. Data analysis is achieved by Utsusemi and IDL.

3. Results

Our main results are plotted in the Figure 1 and 2 below. Figure 1 gives an overall view of phonons mearsured in Bi_2Se_3 and $Sr_{0.1}Bi_2Se_3$. We perform constant-Q slices of low-energy acoustic phonons, both longitudinal and transverse phonons at two Bragg peaks (10-5) and (00-15) have been mapped out clearly. To take a closer look at phonon linewidth, we slice the contour of Bragg peak (00-15) and compare the linewidths in Figure 2. We find an abnormal phonon broadening of acoustic modes along [00L] direction. The linewidths of phonons along [00L] direction is two to four times larger during the broadening, much beyond the instrument resolutions of less than 0.15 meV, indicating an anisotropic electron-phonon coupling in these materials.

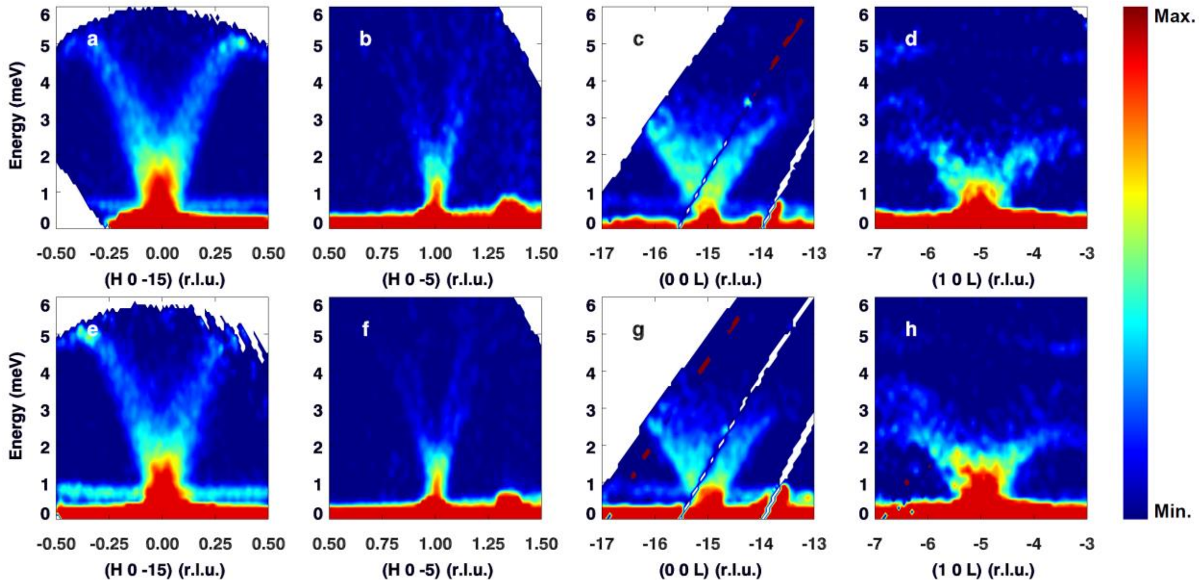

Figure 1. Comparison of phonon dispersions of Bi_2Se_3 (a-d) and $Sr_{0.1}Bi_2Se_3$ (e-h). a and e show the TA mode along [H00] at (00-15); b and f show the TA and LA modes along [H00] at (10-5); c and g show the LA mode along [00L] at (00-15); d and h show the TA and LA modes along [00L] at (10-5). All contours are colored in log scale individually to present clear and comparable dispersions.

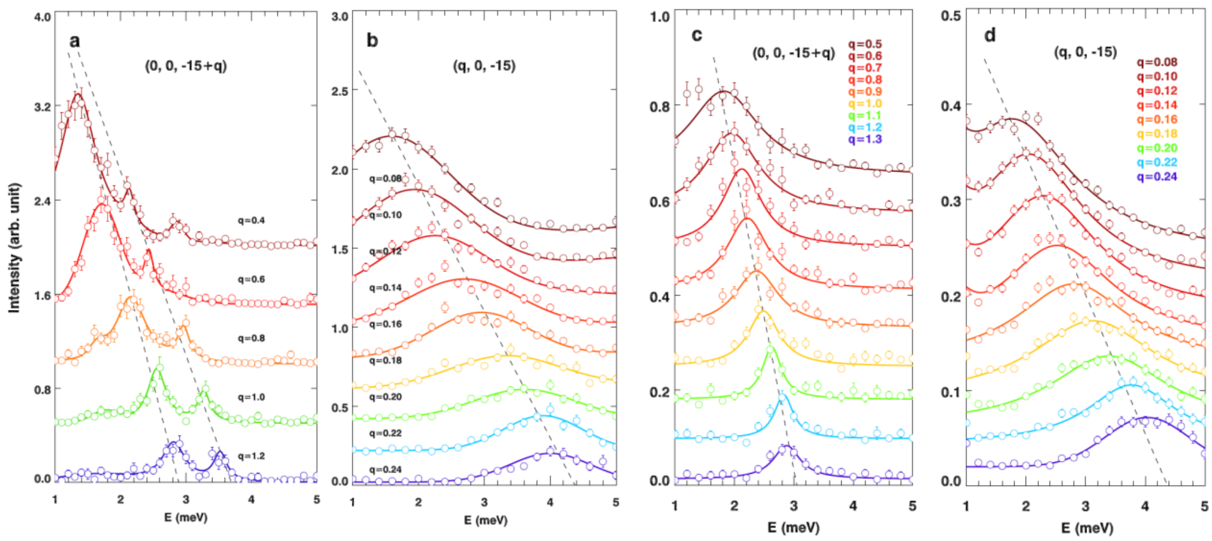

Figure 2. Profiles of the dispersion mappings along [H00] and [00L] direction for Bi_2Se_3 (a, b) and $Sr_{0.1}Bi_2Se_3$ (c, d). Energy scans are taken at (00-15) along [00L] direction (a,c) and [H00] direction (b,d). The intensities of the cuts in a-d are offset to elaborate the dispersions. Solid and dashed lines are guides to eye. The errors are obtained by taking the square root of the actual counts.

4. Conclusion

We find an abnormal phonon broadening of acoustic modes along [00L] direction, indicating an anisotropic electron-phonon coupling in these materials. Our result supports Wan's prediction and suggests that the superconducting doped Bi_2Se_3 may be the first example of phonon-mediated unconventional superconductor.