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High-resolution ARPES study of possible topological superconductors TlxBi2Te3 and Pb/TlBiSe2

著者	Trang Chi Xuan
学位授与機関	Tohoku University
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Ph.D. Thesis

High-resolution ARPES study of possible topological superconductors $Tl_xBi_2Te_3$ and $Pb/TlBiSe_2$

（高分解能 ARPES によるトポロジカル超伝導体候補物質 $Tl_xBi_2Te_3$ および $Pb/TlBiSe_2$ の研究）

Trang Chi Xuan

Department of Physics
Graduate School of Science
Tohoku University
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In this thesis, we have presented ARPES studies of two different types of topological-superconductor candidates, (i) $Tl_xBi_2Te_3$, a superconductor derived from a hole-doped topological insulator, and (ii) a heterostructure consisting of the Pb ultrathin film and the topological insulator $TlBiSe_2$. In this chapter, main conclusions drawn from the present study are briefly summarized.

p-type topological superconductor candidate $Tl_xBi_2Te_3$.

To establish whether or not $Tl_xBi_2Te_3$ is a topological superconductor, we have performed ARPES measurements on the sample at $x = 0.5$, and have suggested that this material is a promising platform of 2D topological superconductor derived from a hole doping to a topological insulator. Main results are summarized below.

(i) **Bulk electronic structure**: To clarify the overall electronic states, we have performed ARPES study of this system by systematically changing the photon energy, and have succeeded in directly determining the electronic structure of bulk bands. From the experimental fact that the bulk Fermi surface consists of several hole pockets, we concluded that $Tl_{0.5}Bi_2Te_3$ is the first case of a superconductor derived by hole doping into topological insulators.

(ii) **Surface state**: The topological surface state is found to be well isolated from the bulk bands and surface chemical potential is tunable over an entire band-gap region. From this result, we concluded that this material is a suitable candidate to realize the 2D topological superconductivity.

2D topological superconductor candidate $Pb/TlBiSe_2$

To explore a new platform of topological superconductor in heterostructure systems, we have fabricated ultrathin Pb films on a topological insulator $TlBiSe_2$, and proposed a new method to realize 2D topological superconductivity without using the superconducting proximity effect. Main results are summarized below.

(i) **Quantum well states:** We have succeeded for the first in in fabricating ultrathin Pb films on top of a topological insulator $TlBiSe_2$. ARPES intensity mapping in the valence-band region clearly confirmed the existence of several quantum well states derived from quantum size effect, confirming atomically flat nature of the Pb film.

(ii) **Topological proximity effect:** The ARPES measurement in the vicinity of E_F around the Γ (bar) point signified strong band hybridization between Pb-derived quantum well states and $TlBiSe_2$-derived topological surface state. This suggests the occurrence of topological proximity effect where that topological Dirac-cone surface states are migrated to the surface of Pb film after interfacing Pb and $TlBiSe_2$.

(iii) **Superconducting gap:** We clearly found a superconducting gap opening at both the migrated topological surface state and the quantum well states of the Pb films. This suggests that this hybrid system becomes a 2D topological superconductor.

To summarize, the present result on $Tl_xBi_2Te_3$ and $Pb/TlBiSe_2$ have added two new categories of 2D topological-superconductor candidates. A next important step for the future studies is to directly resolve Majorana bound state in the vortex core with applying the magnetic field of these exotic systems, using local spectroscopy techniques.