Rashba splitting of Quantum Well State in Pb films induced by Au chains at the interface

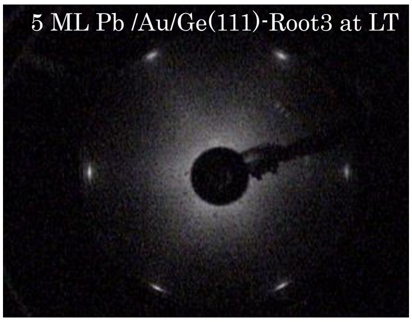
S.-J. Tang[1], Wei-Chuan Chen[1], Sung-Ting Tsai[1], Koichiro Yaji[2], Iwao Matsuda[2]

1. Department of Physics, National Tsing Hua University, Hsinchu, Taiwan 30013, Republic of China
2. Institute for Solid State Physics, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8581, Japan

Our original plan was to study the electronic structure of annealed Pb films on Au/Ge(100)-c(2x8) surface. Then we realized that Pb films on Au/Ge(111)- $\sqrt{3}\times\sqrt{3}$ R30° surface exhibits much more interesting electronic structures; two quasi Dirac cones at the surface zone center were observed for this system. We first grew Pb films by depositing Pb films on Au/Ge(111)-$\sqrt{3}\times\sqrt{3}$ R30° reconstructed surface at T = -140 °C and then annealed Pb films to RT. We found Pb films underwent dramatic phase change from a 1x1 Pb film to a 30° rotated alloy phase as revealed by low energy electron diffraction (LEED) pattern in Fig.1(a) and 1(b).

Fig.2 shows the measured angle-resolved photoemission data of this unique AuPb alloy. As seen, the spectra show two Fermi-Dirac-cone-like structures with linear dispersions at the surface zone center $\bar{\Gamma}$ (One at ~ -0.5 eV and another one at ~-2.8 eV). Their zero effective masses implied the high electric conductivity of the system. The extracted electron velocities of these two cones are 7.56×10^5 m/s 及 4.56×10^5 m/s, respectively, which are close to the values measured from grapheme and topological insulators. This exciting result motivates us to further probe the spin polarization of these two Fermi-Dirac-cone-like structures. Therefore, we then carried out spin-resolved photoemission measurement on these two Dirac-cone-like structures crossing at surface zone center at beamline BL-19A in Photon factory of KEK.

(a)



(b)

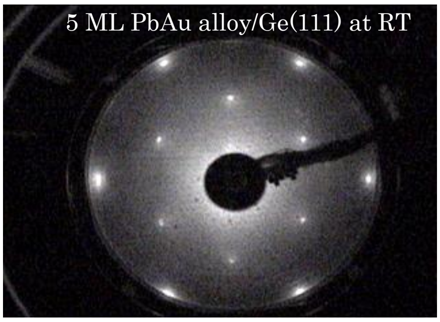


Fig. 1: The LEED patterns of 5 ML Pb /Au/Ge(111)-$\sqrt{3}\times\sqrt{3}$ R30° at LT and 5ML PbAu alloy/Ge(111) at RT

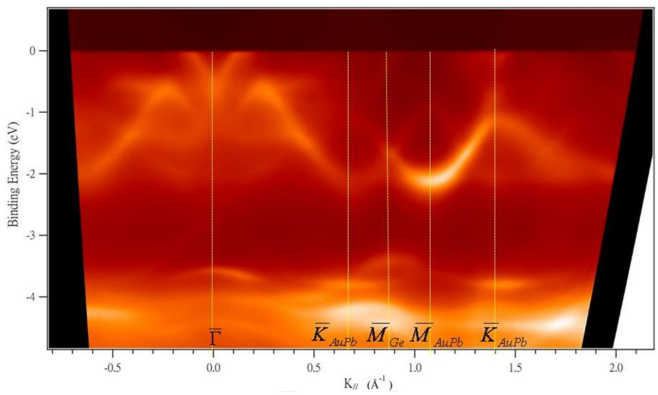


Fig.2: The angle-resolved photoemission spectra of energy band dispersions for 5 ML PbAu alloy/Ge(111) at RT

Fig. 3 shows the partial results, which confirm that the crossing bands constituting the Dirac-cone-like structures are spin-polarized, as shown by the spin-polarized energy distribution curves measured in two opposite spin directions on the surface plane of the sample (blue and red). The peak 1 corresponds to one crossing band of the top Dirac-cone-like structure. As is evident, it shows strong spin-polarization. The peak 2 and peak 3 correspond to the top half and bottom half of the bottom Dirac-cone-like structure. As seen, the crossing band of the top half has opposite spin direction to that of the bottom half. This result exhibits the typical behavior of topological-insulator Dirac cone that the rotation direction of the spin on the top half is opposite to that of the bottom half. It is very interesting to note that from the 2D photoemission spectra, one can see there is an overall energy gap roughly between -2 and -4 eV. Pb *sp* electrons dominate the energy range above -2 eV and Au *d* electrons dominate the energy range below -4 eV. It is likely that the bottom Dirac-cone-like structure comes from *spd* hybridization between Pb and Au. Therefore, the bottom Dirac-cone-like structure is very likely to be a new type of topological-insulator Dirac cone which has *d* electrons involved. Looking for a new generation of topological-insulator materials with *d* or *f* electrons involved for Dirac cones is currently one of the main goals in this strong competing battle field of topological-insulator. Nevertheless, a more detailed spin-resolved photoemission measurement in all directions of kxky plane will have to be done in Photon factory of KEK to uncover the whole picture of the spin texture.

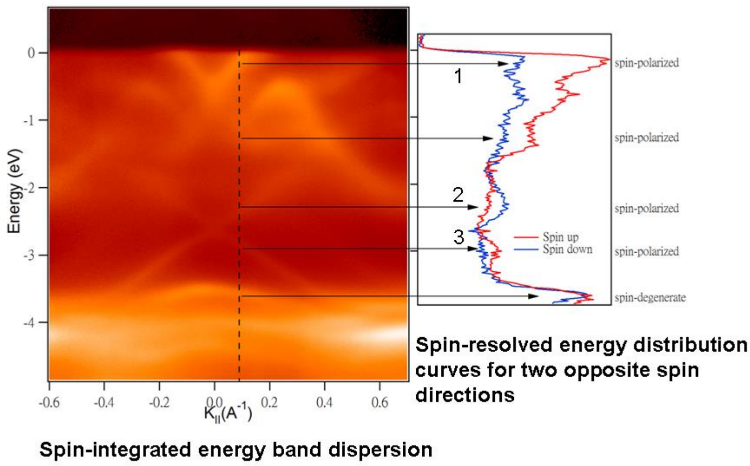


Fig.3: The correspondence between angle-resolved photoemission spectra and spin-resolved photoemission spectra for 5 ML PbAu alloy/Ge(111) at RT