Bilayer Oscillation of Subband Effective Masses in Pb/Ge(111) Thin-film Quantum Wells

Shu-Jung Tang (唐述中)[1,2], Chang-Yeh Lee (李昌曄)[2],
Chien-Chung Huang (黃建中)[1], Rong-Tay Chang (張榮泰)[1], Cheng-Maw Cheng (鄭澄懋)[2],
Ku-Ding Tsuei (崔古鼎)[1,2], and Hong-Tai Jeng (鄭弘泰)[1,3]

[1]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan
[2]National Synchrotron Radiation Research Center, Hsinchu, Taiwan
[3]Institute of Physics, Academia Sinica, Taipei, Taiwan

Subband dispersions of quantum-well states (QWS) in Pb thin films on Ge(111) have been measured with angle-resolved photoemission spectroscopy (ARPES). The effective masses at the surface zone center exhibit a bilayer oscillation with thickness, in both magnitude and sign. This behavior is attributed to a strong interaction between Pb quantum-well subbands and the Ge valence maximum near the Fermi level, which occurs about every two monolayers.

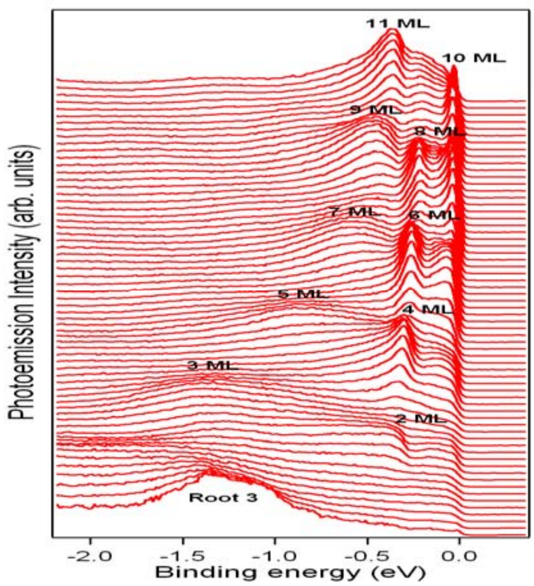

Fig. 1: Photoemission spectra at normal emission taken from Pb films of thicknesses from 0 to 11 ML on the Pb/Ge(111)-$\sqrt{3}\times\sqrt{3}$ R30° surface

Figure 1 shows the energy distribution curves (EDC) of QWS at normal emission for films of thickness from 0 to 11 ML Pb films on the Pb/Ge(111)- $\sqrt{3}\times\sqrt{3}$ R30° surface. Each EDC was measured after Pb deposition for one minute at a steady rate ~0.2 ML/min. The QWS signals have maximum intensity at integer layers. It is clear from the spectrum that, when the intensity of the QWS signal corresponding to *N* ML decreases, the signal corresponding to *N*+1 ML begins to emerge. This behaviour demonstrates that the films grow layer by layer. According to our thickness calibration, the first QWS signal to emerge is at 2 ML, indicating a critical thickness. Moreover, the energy positions of QWS signals evolve with increasing thickness in a zigzag way from 2 ML to 11 ML; the QWS associated with even layers are nearer the Fermi level than those associated with odd layers. Moreover, the QWS peaks for 2, 4, 6, 8, 10 ML split into two components because of a strong interaction with Ge band edges at the valence maximum near the Fermi level. This strong interaction further affects the in-plane dispersion of QWS, as revealed by the effective mass. The origin of the interaction is hybridization, but previous work on Ag/Ge(111) showed that the Anderson many-body interaction between the discrete QWS and continuous bulk electronic states should be taken into account for a complete simulation of the distorted dispersion. Because the Ge valence maximum is near the Fermi level, the QWS observed are resonances. The QWS peaks marked with the thickness in Fig. 1 are those for which we have investigated the subband dispersions.

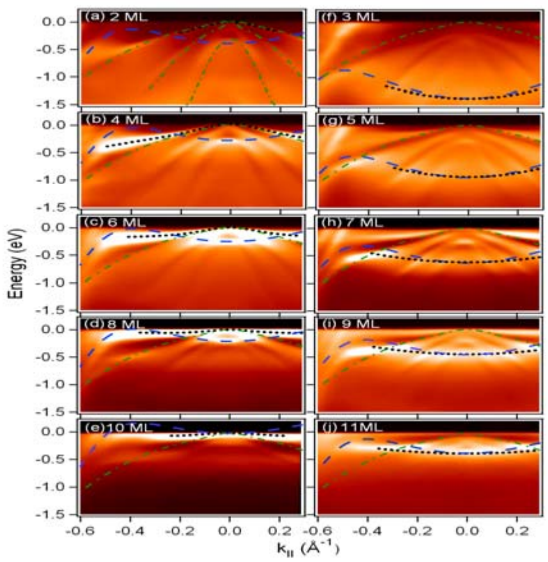

Fig. 2: Angle-resolved photoemission spectra for Pb films ranging from 2 ML to 11 ML in the symmetry direction from $\bar{\Gamma}$ to $\bar{K}$ are presented as a grey-scale image.

Figure 2 shows the 2D ARPES spectra of QWS subbands in the symmetry direction from $\bar{\Gamma}$ to $\bar{K}$ for Pb films of thickness from 2 to 11 ML. The subband dispersions of the odd and even layers about the surface zone center ($k_{\|} = 0$) differ substantially. Near the zone center, the band dispersions of the even layers are downward parabola-like curves, whereas, for odd layers, the Pb band dispersions are similar to upward parabolas with distortion near the Ge band edges at the off-normal positions.