Ge 再構成表面上に作成した Bi 原子層のフェルミレベル近傍における電子状態

今村真幸、松石鉱太朗、山本勇、東純平、高橋和敏
佐賀大学シンクロトロン光応用研究センター

Ⅳ族半導体であるゲルマニウムやシリコン上に数層の金属を蒸着させて作成した超構造は、スピン軌道相互作用により特異な表面電子状態を示すことから次世代スピントロニクス材料への応用や基礎物性の観点から盛んに研究が行われてきた。半導体表面への金属原子吸着による電子状態制御において，その電子状態及び電気伝導に関する知見は重要であると考えられるものの、それらに大きく寄与するフェルミレベル直上の非占有電子状態や電子遷移過程に関する報告例は非常に少ない。そこで、本研究では Ge (111)-c2x8 再構成表面上に作製したビスマス原子層について、角度分解光子光電子、角度分解 2 光子光電子分光法を用いた実験的研究を行った。得られた光電子スペクトルについて詳細な解析を行うことにより、フェルミレベル近傍における占有・非占有電子状態のエネルギー分散及び電子遷移過程について明らかにした。

Ge再構成表面上に作成したBi原子層のフェルミレベル近傍における電子状態

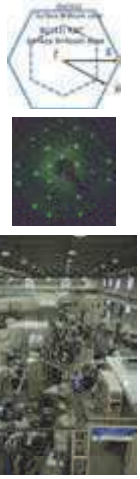
今村真幸、松石鉱太朗、山本勇、東純平、高橋和敏
佐賀大学シンクロトロン光応用研究センター

Introduction

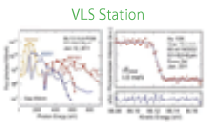
Atomic layer grown on semiconductor surface attracts much attention, since they exhibits characteristic electronic and spintronic properties.
Various phases and physical properties are obtainable with the combination of layer atoms and substrates. In contrast to an understanding of the occupied electronic states, the reports for electronic states in the unoccupied state which associated with their properties such as the electron transport phenomena are very few to date.
In this work, we have performed ARPES and AR2PPE study of Ge(111)-Bi$\sqrt{3}\times\sqrt{3}$ surface. From the results of detailed analysis, the electronic dispersions in the vicinity of Fermi-level were elucidated.

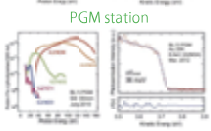
Experiments

- Angle-resolved photoemission with synchrotron radiation
Excitation energy : 21eV, Temperature: 35K
- Angle-resolved two-photon photoemission
Excitation source : Ti:sapphire laser (Chameleon, COHERENT Co.)
Excitation energy : 3.96 - 4.43 eV(THG), Repetation rate: 80 MHz,
Intensity: ~ 0.15 nJ, Temperature: 35K
- All the elxperiments were carried at Saga university beamline in SAGA-LS



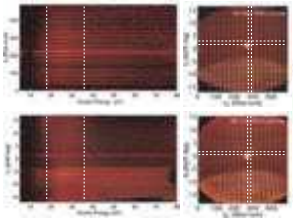
Saga University Beamline



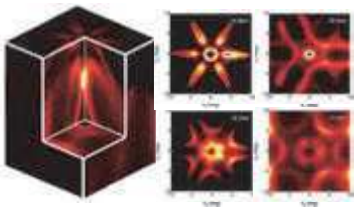


○Synchrotron radiation (undulator BL and bending magnet BL)
○Ti:Sapphire laser system : unoccupied state investigation and excited-electron dynamics with time-resolved measurement
○Deflector equipped electron analyzer

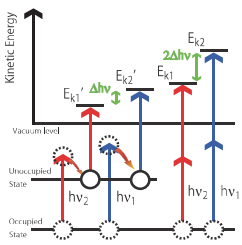
Evaluation by 1 degree step lattice and e-beam.
- EPass 20 slit 0.2mm L4Ang0d8 (±15deg)



Bi(111) grown on Si (111) Exc. Eng. 21 eV



Two-photon photoemission process in AR2PPE

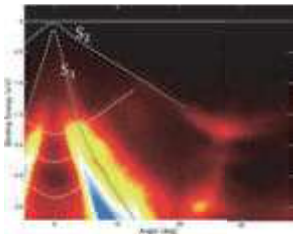


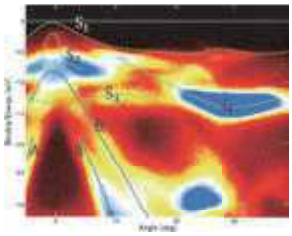
Occupied states derived features: follows 2Δhν
$E_{k1}=h\nu_1+h\nu_1-\Phi$, $E_{k2}=h\nu_2+h\nu_2-\Phi$
$\Delta E_k=E_{k1}-E_{k2}=2h\nu_1-2h\nu_2 \rightarrow \Delta E_k=2\Delta h\nu$
Unoccupied states derived features: follows Δhν
$E_{k1}'=h\nu_1-\Phi$, $E_{k2}'=h\nu_2-\Phi$
$\Delta Ek=E_{k1}'-E_{k2}'=h\nu_1-h\nu_2 \rightarrow \Delta Ek=\Delta h\nu$

Based on the energy conservation rule in the photo exicitaion process, the origins of the obtained dispersions and their energies from Fermi-level are specified.

ARPES spectra with synchrotron radiation

Ge-Bi$\sqrt{3}$x$\sqrt{3}$ Ge(111)-c2x8

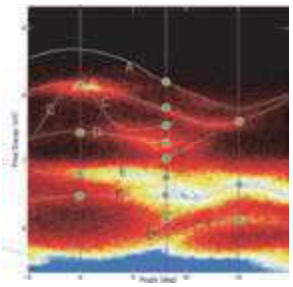


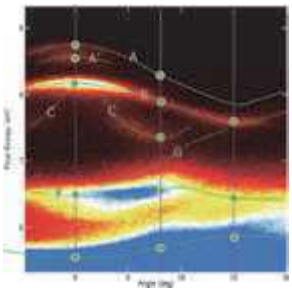


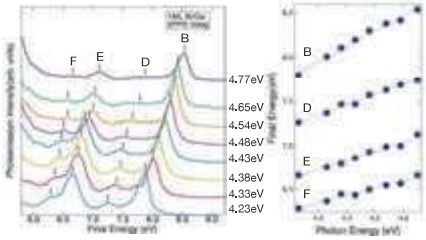
Energy dependence of ARPES specta measured with synchrotron radiation reveals the origins of spectral features. Features S1-S3 are located in the same energy for different excitation energy excitation, and attributed to surface states Additional features observed only for ARPES spectrum of Ge-Bi$\sqrt{3}$x$\sqrt{3}$ were assigned as the surface states derived from Bi.

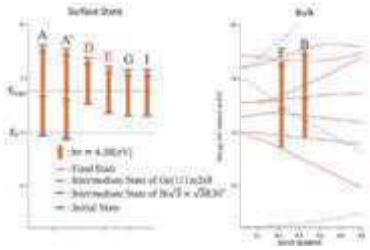
AR2PPE spectra

Ge-Bi$\sqrt{3}$x$\sqrt{3}$ Ge(111)-c2x8









Peak A and A' : with the slopes of 2
Energies with respect to Fermi-level are consistent with the energies for S1 and S2 those obtained by ARPES.
Attributed to surface state S1 and S2 in the occupied states observed in ARPES for Ge.

Peak C, G, and I : with the slope of 1
These peaks were found in AR2PPE both spectra for Ge-Bi$\sqrt{3}$x$\sqrt{3}$ and Ge.
Assigned as the unoccupied state of Ge(111) derived surface state.

Peak D and E: with the slopes of 1
Peaks were not observed in the AR2PPE spectra for Ge (111) -c2x8.
Assigned as the unoccupied surface-states derived from Bi layer.

Peak B and F : slopes are not integer
These peaks were found in AR2PPE both spectra for Ge-Bi$\sqrt{3}$x$\sqrt{3}$ layer and Ge.
The band dispersion perpendicular to surface direction based on the previously reported calculation, these peaks are assined as the optical transition in bulk-bands of Ge.

Conclusion

Electronic dispersions above and below Fermi-level for Bi$\sqrt{3}$x$\sqrt{3}$ layer on Ge(111)-c2x8 were investigated with AR2PPE spectroscopy.
Obtained excitation-energy-dependence of AR2PPE spectra were elucidated based on the energy conservation in the two-photon photo excitation process.
Observed spectral features were assigned as the transition between bulk band, occupied-, and unoccupied-electronic dispersion.