18A/2005G089

Quantum confinement in uniform GeSn alloy nanodots on a SiO_2 monolayer

Yasuo NAKAYAMA*[1], Keiko TAKASE[2], Toru HIRAHARA[1,2], Iwao MATSUDA[1,3], Shuji HASEGAWA[1,2], Yoshiaki NAKAMURA[1,4], Masakazu ICHIKAWA[1,4]
[1]CREST, Japan Science and Technology Agency, Kawaguchi, Saitama 332-0012, Japan
[2]Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan
[3]ISSP, The University of Tokyo, Kashiwa, Chiba 277-8581, Japan
[4]Graduate School of Engineering, The University of Tokyo, Tokyo 113-8656, Japan

Introduction

Because a GeSn alloy will change into a direct-gap semiconductor when the composition ratio of Sn is at a critical value (0.10-0.13) [1], it has been considered as a candidate for light-emitting devices composed of group-IV semiconductors. However a segregation tendency of Sn from Ge due to limited solid-solubility makes it difficult to produce a uniform alloy with an intended stoichiometry. Recently, Nakamura *et al.* succeeded to produce hemispherical nanodots of a super-saturated GeSn alloy through co-deposition of Ge and Sn onto a Si substrate covered by a SiO_2 monolayer with pre-deposited Ge nuclei [2]. The size of them is small enough to realize quantum confinement phenomena and is controllable by changing the deposition amount. The present GeSn nanodots will therefor be promising for optoelectronics application if segregation of Sn does not occur, which is needed to realize a direct-gap condition.

In the present study, we conducted core-level and valence-band photoemission spectroscopy (PES) of the GeSn nanodots on the SiO_2 monolayer for the sake of confirming no Sn segregation and occurrence of the quantum confinement on identical nanodot arrays.

Experimental

The Si substrate was cut from a mirror polished *n*-type Si(111) wafer (1-10 Ωcm) followed by conventional cleaning procedures in ultrahigh vacuum (UHV) to prepare a clean Si(111) 7×7 surface. The SiO_2 monolayer and GeSn nanodots were fabricated by the reported procedures [2,3] which are schematically shown in Fig. 1. Ge and Sn were deposited by resistive heating to tungsten filaments surrounding graphite tube cells, where the evaporation rates were set at 0.22 BL/min (bilayers per minute) for Ge and 0.04 BL/min for Sn. On analysis, the coverage was converted into the corresponding average dot-size by using previously reported relationship [2,4]. PES experiments were carried out at KEK-PF BL-18A. The photon energies were tuned at 55 eV for Ge-3*d* and Sn-4*d* whereas at 21.2 eV for the valence band. All the spectra were taken at normal emission angle.

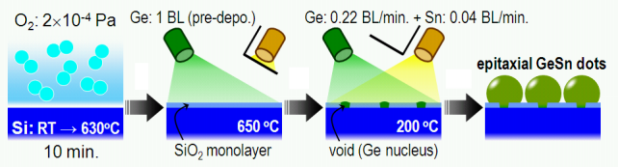

Fig.1: A schematic drawing of the procedures to fabricate the SiO_2 monolayer and GeSn nanodots.

Results and Discussion

The composition ratio (stoichiometry) of Ge and Sn was estimated from peak intensities of Ge-3*d* and Sn-4*d* PES spectra multiplied by each photo-ionization cross-section [5], as shown in Fig. 2(a). Although the data show apparent scattering, the estimated stoichiometry looks staying around the intended ratio of (Ge:Sn) = (0.85:0.15) independent of the dot radius. In addition, Sn-4*d* peak can be fitted by a single component of a reasonable peak-width by using reasonable fitting parameters as shown in the inset of Fig. 2 (inset). These results suggest no Sn segregation at surfaces of the nanodots.

The valence band maximum (VBM) of the nanodots, which was defined as an intersection of two fitting lines of the spectral tail and background signals, showed systematical shift toward the Fermi level as increasing the dot-size. It is a clear sign of the quantum confinment. By adopting analytical solution of confinment by a spherical harmonic potential, substancial confining potential barrier height (for holes) is evaluated as 2.0 ± 0.9 eV from the slope of the plot shown in Fig. 2(b), which is in good accordance with the reported value for Ge nandots [6].

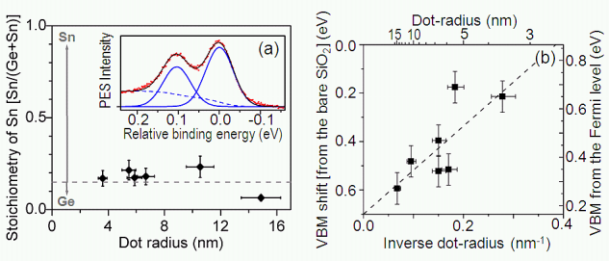

Fig.2: (a) Stoichiometry of the nanodots. (Inset) Typical Sn-4*d* PES spectra of the nanodots. (b) Energy shift of the VBM of the nanodots from that of the bulk Si underneath the bare SiO_2 monolayer plotted as a function of inverse dot-radii.

References

[1] H.P.L. de Guevara et al., Appl. Phys. Lett. 84, 4532 (2004).
[2] Y. Nakamura et al., J. Appl. Phys. 102, 124302 (2007).
[3] A. A. Shklyaev et al., Phys. Rev. B 62, 1540 (2000).
[4] Y. Nakayama et al., Jpn J. Appl. Phys. Pt.2 46, L1176 (2007).
[5] J.J. Yeh et al., Atom. Data Nucl. Data Tables, 32, 1 (1985).
[6] A. Konchenko et al., Phys. Rev. B 73, 113311 (2006).

* Present address: Center for Frontier Science, Chiba University; nkym@restaff.chiba-u.jp