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Change in conductivity through the space-charge layer of the Si substrate induced by Ge nanodot arrays probed by means of Si-2*p* photoemission

Yasuo NAKAYAMA*[1], Hiroyuki OKINO[2], Toru HIRAHARA[1,2], Iwao MATSUDA[1,3],
Shuji HASEGAWA[1,2], 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

Ge nanodots formed on a SiO_2 monolayer covering Si surface have been considered as a promising material for optoelectronics [1]. One can separately fabricate two types of nanodots by controlling the growth condition; epitaxial and non-epitaxial. The former has sub-nanometer-sized voids in the interface oxide layer beneath the nanodots, which makes direct contact to the substrate, whereas the latter has no void causing separation of the dots from the substrate. Quantum size effect in the nanodots was revealed by means of valence band photoemission [2,3], and quantitative analysis on shift of the quantized energy as a function of dot-size shows a lower confining potential barrier height for the epitaxial nanodots compared with the non-epitaxial ones [2]. Recently, significant enhancement of electrical conductance on the epitaxial dot arrays compares to the non-epitaxial ones was elucidated by means of micro 4 point probe and 4-tip STM, which implies effective carrier exchange through the voids between the epitaxial nanodots and the substrate [4]. Generally speaking, however, such enhancement of the conductivity can also be ascribed to a change in band-bending of the Si substrate. In this context, we evaluated the change in the conductance through the space-charge (SC) layer of Si substrate from band-bending modification after formation of the two types of Ge nanodots.

Experimental

Samples were cut from an n-type Si(111) wafer (1-10 Ωcm). The SiO_2 monolayer and the nanodots, the epitaxial and non-epitaxial, were prepared by the same procedure as reported before [1-3]. Photoemission spectroscopy (PES) experiments were carried out at KEK-PF BL-1C and 18A. All the spectra presented below were taken at normal emission angle (hν = 140 eV).

Results and Discussion

Si-2*p* PES spectra of the epitaxial and non-epitaxial Ge nanodots are shown in Fig.1(a) with those of the SiO_2 monolayer and clean Si(111) 7x7 presented for comparison. Although the ultrathin SiO_2 film reveals slight shift of Si-2*p* peak position from the 7x7 surface, Ge deposition on the oxide layer makes the peaks move to lower binding energy even when the deposited Ge is separated from the Si substrate by the oxide layer (in cases of the non-epitaxial Ge nanodots). From the change of Si-2*p* peak positions, we can track a shift of valence band maxima (VBM) of the Si substrates against that of clean Si 7x7 [0.63 eV from the Fermi level (E_F)] [5]. The VBM shift of the Si substrates after formation of the Ge nanodots is shown in Fig.1(b). By solving Poisson's equation, one can evaluate the change in the electric conductivity through the SC layer of the Si substrate after formation of the nanodots from the present results. In the present case, the estimated changes in the SC layer conductivity are negative instead of conductance gain for the both types of nanodots. It points out that the observed conductance enhancement is ascribed not to the change in the conductivity of the SC layer but to generation of the additional conduction paths originate from the voids at the oxide layer as well as the nanodots themselves.

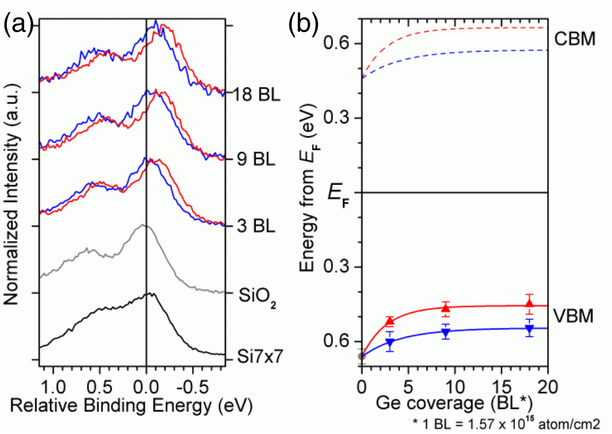

Fig.1: (a) Si-2*p* PES of the epitaxial (red) and non-epitaxial (blue) nanodots at noted Ge coverage presented with those of SiO_2 monolayer (gray) and clean Si 7x7 surface (black). (b) VBM position from E_F plotted with error bars as a function of Ge coverage. Solid lines are fitting curves. Conduction band minima (CBM) calculated under fixed gap-width condition (E_{gap} = 1.12 eV) are also presented as broken lines.

References

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