Standing-Wave Hard X-ray Photoemission Spectroscopy (SW-HXPS) study of free standing InAs quantum membranes (QM)

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Standing-Wave Hard X-ray Photoemission Spectroscopy (SW-HXPS) is a versatile and non-destructive method for characterizing in a quantitative way not only multilayers and superlattices but also materials transferred onto synthetic multilayer mirrors. In this study, we characterize a free standing InAs thin film quantum membrane (QM) chosen as a model for the more general class of quasi2D semiconductors. III-V compound semiconductors like InAs possess superb carrier transport and excellent optoelectronic properties, which render them good candidates for high performance electronic and optoelectronic devices [1]. However, the growth of these high performance semiconductors and their integration with the low-cost processing of Si technology present challenges since high defect densities and junction leakage currents occur at the interface between these compounds and the Si substrate. In order to overcome these problems, free-standing InAs QMs were transferred onto a (SiO_2/[Si/Mo]$_x$) multilayer mirror substrate. These free-standing ultrathin films and their interfaces have not been fully characterized. The characterization of these interfaces is fundamental, since possible formation of oxide layers on the surface or at the interface with the substrate strongly influence their electronic transport properties. In this study information on the chemical composition and on the chemical states of the elements within the InAs (QM) was obtained by HXPS and on the quantitative depth profiles by SW-HXPS. Furthermore, by comparing the experimental SW-HXPS rocking curves to x-ray optical calculations [2,3], the chemical depth profile of the InAs(QM) and its interfaces were quantitatively derived with Angstrom precision. We determined that the exposure to air induced the formation of an $InAsO_4$ layer on top of the stoichiometric InAs(QM) and that the interface between them is not sharp, indicating interdiffusion between these two layers. On the other hand, the bottom interface between the InAs(QM) and the native oxide SiO_2 on top of the (Si/Mo) mirror is abrupt. In addition, the valence band offset (VBO) between the InAs(QM) and the SiO_2/[(Si/Mo)x] substrate was determined by HXPS. The value of VBO = 0.2±0.04 eV is in good agreement with literature results obtained by electrical characterization, demonstrating a well-defined and abrupt InAs/SiO_2 heterojunction [4]. In conclusion, we have demonstrated that HXPS and SW-HXPS are non-destructive, powerful methods for characterizing interfaces and for providing chemical depth profiles in quantum membranes, 2D layered materials, and other layered nanostructures.

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