Surface and Interface Research

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【Staff Members】

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【Research Activities & Plan】

In academic year 2004, Dr. Nagao's group continued the STM/LEEM investigation of the thin film Bi growth on the Si (111)-7×7 surface to elucidate the mechanism of coverage-dependent phase transition of the Bi ultra-thin film. We concluded with the help of theory group in NIMS that the Bi film has a unique new phase, which stays stable up to the film thickness of 4 monolayers. The bonding configuration of this phase is similar to black phosphorus which belongs to the same elemental group as Bi, but has been never observed in bulk Bi. (**Ref.** ***1***) We wishfully hope that this new allotrope of Bi may possibly be accompanied with exotic electronic properties, realizing unique Bi properties. We plan to investigate it in the coming year, although Dr. Nagao left our group in September 2004 to take a position at NIMS, Tsukuba.

The main thrust of our group for last couple of years is Ge (105)/Si project mainly performed by Dr. Fujikawa and his students. Realizing its rather complicated nature of the surface structure due to large charge transfer, they used high-performance atomic force microscopy (AFM) to nail down the details of atomic structure of Ge (105)/Si in collaboration with Dr. Hasegawa's group at ISSP, University of Tokyo. (**Ref.** ***2***). They found that the obtained AFM images documented the exact positions of the dangling bonds on the surface with the resolution even higher than the best STM images currently available. Furthermore, using the Kelvin force microscopy together with the AFM, an atomically-resolved potential map was successfully resolved on the surface, which rendered additional support to the structure model we proposed. To our best knowledge, this is the first atomically resolved potential mapping obtained using this unique technique. These results nicely exemplify the powerfulness of AFM in surface structure. This research was extended to further investigate hydrogen adsorption and they have found that the surface strain on this surface is controllable by the hydrogen adsorption. (PRL 94, 086105 (2005).) This work implies the possibility of strain control of Ge quantum dots on Si through adsorption. Use of "surface strain" as a controllable parameter in surface engineering will be our major area of research for the coming years. For instance, we plan to investigate in what degree we can modify the strain in the Ge films and nanostructures by adsorption in order to control mechanical and electronic properties of the Ge/Si system.

Highly challenging "growth of GaN on Si" was attempted by Dr. Yamada-Takamura's group using the UHV molecular beam epitaxy (MBE)-SPM system. GaN is grown on Si (111) by radio-frequency plasma-assisted MBE, and the growth front is studied using reflection high-energy electron diffraction (RHEED) and STM. By successfully documenting the optimum nucleation/growth conditions, well-defined surface reconstructions, i. e. GaN-(000-1)-3×3, 6×6, and c(6×12), are observed by STM after the additional Ga deposition at ambient., indicating the uniform N-polarity of the grown film. They have concluded that the initial GaN nucleation under N-rich conditions is crucial to grow mono-polar uniform GaN films on the Si substrate (APL 87, 032110(2005)). We currently extend this GaN/Si system research to include ZrB_2 buffer layer for better GaN film growth. We also plan to study diamond surfaces by UHV non-contact-AFM.

Dr. Wu worked successfully to document the two dimensional nature of alkali metal adsorbate on the Si (111)-7×7 surface at low coverage and formation of magic cluster upon the critical coverage of 4 atoms/unit cell.. This work was further augmented by low-temperature STM study to control the movements of alkali-metal atoms on the surface. These results were in complete agreement with the theoretical potential mapping and computer simulation of STM data by Kawazoe-Lab. (**Ref.** ***3***) Dr. Wu left our group to take up a professorship at Institute of Physics, Chinese Academy of Sciences, Beijing in January 2005.

Halogen (Cl, F) etching of the GaN(000+1) surface is being continuously studied in connection to its technological importance in device fabrication process by Dr. Fujikawa's group. This work is part of S. Kuwano's Ph.D. thesis research. They found, among others, that the Ga-rich condition is essential to efficient etching of the GaN surface using chlorine. (**Ref.** ***4***)

In LEEM/STM study by Dr. Sadowski's group, well ordered bismuth films on Si (111) were used as templates for the growth of thin organic films of pentacene. Making a good use of low-energy electron microscopy (LEEM) and STM, they found that pentacene nucleates on the Bi (001) substrate into a highly ordered, bulk-like crystalline layer, with the molecules "standing up" on the Bi surface, with the (001) plane as the growth front. Moreover, the Pn layer is aligned epitaxially with the Bi (001) surface having a "point-on-line" commensurate relation with the substrate, which is the first report on the epitaxial growth of pentacene. It was also found that the Pn/Bi (001) film crystallizes in the bulk-like structure directly from the first Pn layer, and that the diameter of the first-layer Pn islands exceeds as much as 200 mm, one of the largest pentacene islands reported up to date. (APL 86, 073109 (2005)) As an ongoing joint work with Professor Nakajima's group in this area, perylene-3.4.9.10-tetracarboxylic dianhydride (PTCDA) thin film grown on the hydrogen-terminated, vicinal Si (111) substrate was investigated by UHV STM, and the possible adsorption model has been proposed, in which the long axis of the 2D unit cell of PTCDA matches the vector (6, 2) of the H-Si(111) surface, and PTCDA lattice has a point-on-line coincidence with the H-Si (111) lattice. (**Ref.** ***5***) In the coming year we plan to extend our activities onto studying the growth mode, crystallographic and electronic transport properties of other organic thin films, such as perfluoropentacene, pentacene-quinone and rubrene.

We also note profitable collaboration in various researches with Professor Chen's group at IFCAM.

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