Advanced Substrate for Fabrication of Nanostructures with XHV Integrated Process.

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Abstract

The fabrication of advanced material with an atomic scale manipulation requires the advanced substrate suitable for epitaxial growth without the effect by the substrate lattice structure and the atomically super clean environment for the atomic scale continuous manipulations on the substrate. Hexagonal boron nitride (h-BN) film could be successfully prepared by the surface segregation method with cosputtering preparation system. The c surface of prepared h-BN film parallel to the base substrate surface can offer van der Waals' gap with little attractive force and can be the advanced substrate for fabrication of advanced material with nanoscale manipulation due to little atomic influence by the substrate. The extreme high vacuum integrated process for the fabrication of advanced material in an atomic scale was successfully developed. The integrated process consists of main line, branch line and couplings for the connection of main and branch lines. The linear motor transport levitated by attractive electromagnetic force is installed in the main line and the superconducting transport levitated by the superconductor pinning effect is installed in branch line. The pressure change less than 10^{-10} Pa could be accomplished during the sample transfer without surface contamination due to the levitation transfer systems.

Introduction

One of the base technology for the fabrication of advanced material with an atomic scale manipulation is the advanced substrate suitable for epitaxial growth without the effect by the substrate lattice structure[1] and the atomically super clean environment for the atomic scale continuous manipulations on the substrate[2].

The obstacle of fabrication of nano-structure is atomic lattice mismatch between consistent materials. The lattice mismatch condition will be drastically relaxed in the growth process with van der Waals' interactions. The layered material can be suitable for the growth process with van der Waals' interaction and can be the excellent substrate to promote epitaxial growth of nano-structure due to van del Waals' force on the material surface. Boron nitride with hexagonal crystal structure (h-BN) have the c surface with van der Waals' interaction and the c plane of h-BN layer parallel to the base substrate can offer van der Waals' gap at the interface between grown material and the layer with little atomic mismatch. The extreme high vacuum (XHV) integrated process can offer atomically clean environment during multi-operations necessary for nano scale material fabrication due to the super clean atmosphere of little gas molecules during the total operations and handling for material processing and analyses by means of lexitaion transport system[3].

The research is carried out, therefore, on the fabrication of the advanced substrate with h-BN for the smooth creation of advanced materials with atomically controlled structure which will exhibit quantum phenomena and the construction of super clean XHV integrated process for the continuous fabrication of nano structure.

Experimental

Advanced substrate for nanostructure growth

Hexagonal boron nitride structure as promising compound for advanced substrate is formed on the substrate material by low temperature segregation[4] on the surface of co-sputtered film substrate with BN and alloy, stainless steel and copper. The surface of the h-BN film prepared with helicon radio frequency magnetron sputtering deposition system is evaluated with scanning auger electron microscope (SAM), X-ray photoelectron spectroscopy (XPS), reflection high energy electron diffraction (RHEED), thermal desorption spectroscopy (TDS) and electron simulated desorption[5] (ESD) to check the low interaction among the surface and adsorbed gas molecules.

Extreme high vacuum integrated process for nano structure fabrication

An XHV integrated process is planned to be developed in order to transfer samples long distances from one instrument to another without any contamination by gas adsorption on the ultraclean surface[3]. The process consists of vacuum chambers, pumps, gauges, gate valves, transports and so on as shown in Figure 1. The process has three intro-chambers to join chambers for instruments. Magnetic levitation transports are installed into the process because they have no sliding part to generate dust particles and outgassing. One transport in the main track chamber electromagnetically levitates a carrier and transfers it by linear motor drive for long distance transport. The other transport in a sidetrack chamber levitates a carrier by $YBa_2Cu_3O_{7-x}$ superconducting magnet discs and mechanically transfers it for tough transport required in the sample delivery between carrier stage and sample stage in connected instrument. The XHV integrated process are aimed to deliver samples from one intro chamber to another without such any atomic contamination on the surface as gas molecule adsorption.

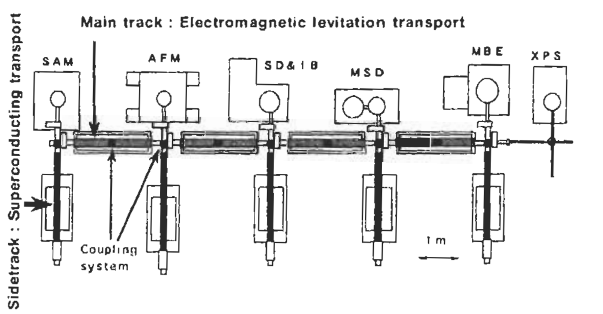

Fig.1 Schematic of an extreme high vacuum integrated process

Result and Discussion

Advanced substrate for nanostructure growth

Figure 2 (a) shows that the shapes of Auger peaks of boron (B) and nitrogen (N) on the steel and copper substrate are similar to those of boron nitride. The binding energy values of the K level of B and N on the substrate are 190.3 eV and 397.9 eV respectively with XPS. The values are well in agreement with those of sintered BN target disc measured by the XPS. Therefore, it is concluded that BN segregated on the surface of substrates.

The RHEED pattern of BN segregated layer in Fig.2(b) shows very week diffraction rings and strong spots ordering by mirror reflection. The diffraction rings of polycrystal come from hexagonal BN basal plane of c axis orientated to the surface normal. The diffraction image shows that h-BN layers had the preferred orientation and tended to cover the segregated surface with the basal plane (0001). It is founded that co-sputtered deposition of BN and metal can segregate BN with hexagonal structure with the c plane parallel to the substrate surface.

Copper substrate was found to segregate h-BN on the surface as sputtered without annealing different from the case of h-BN on stainless steel which was required vacuum annealing at more than 600K. The result so far shows the one step to establish the fine control of co-sputtering method for the fabrication of advanced substrate though the issue to be worked out is that the surface coverage of the segregated h-BN on the copper substrate did not reach 100% and that the c plane direction of the BN has still a little deviations on the steel substrate.

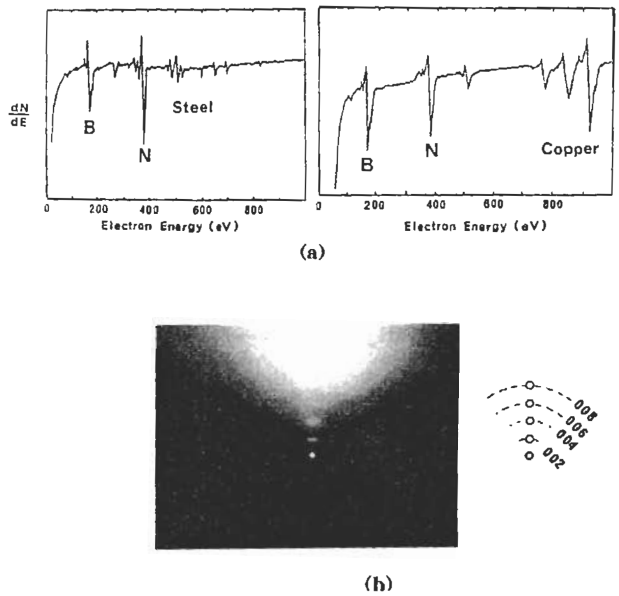

Fig.2 Auger spectra of segregated h-BN on substrates(a) and the RHEED image(b).

The evaluation of van der Waals' force on the surface of segregated h-BN was carried out with TDS and ESD. TDS spectra of stainless steel substrate without BN layer and one with BN layer shows that desorbing hydrogen of H_2^+ and H^+ on the substrate with h-BN layer is one tenth smaller than the substrate without h-BN layer.

Figure 3 shows EDS mapping of H^+ ions which is measured in 10^{-5} Pa hydrogen atmosphere. Light points are desorbed ions. Comparing of part (b) with (a) shows that the substrate without h-BN is bright and that the substrate with h-BN is dark. Hexagonal BN has a low adsorption rate of H due to small van der Waals' force on the surface.

Desorbing molecules of CO (m/e=12) and H_2O (m/e=18) on the substrate with h-BN layer is shown in Fig.4 and this also shows that h-BN as a low adsorption rate of H due to small van der Waals' force on the surface.

The summarize of these results concludes that the surface of segregated h-BN has small van der Waals' force and can be a promising candidate substrate for nano scale structure fabrication as shown in Fig.5.

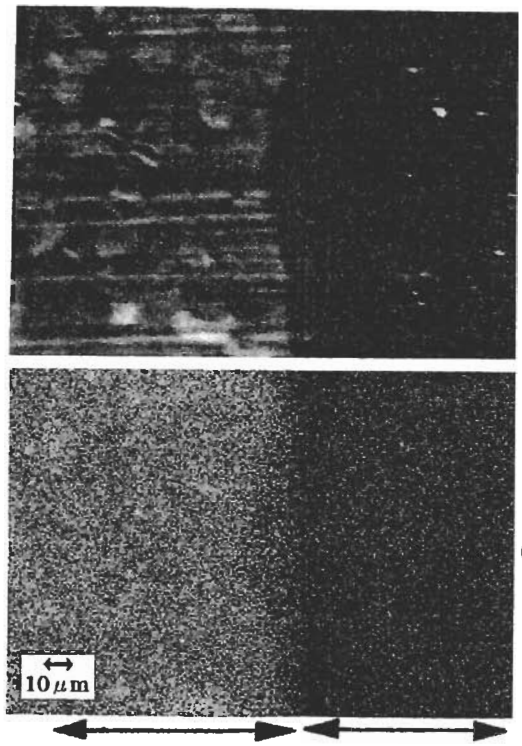

Fig.3 ESD mapping of H+ ions

Extreme high vacuum integrated process for nano structure fabrication

A sample is delivered from the carrier of the sidetrack line to the carrier of the main track line by lifting up and down hoist system. Pressure of 9×10^{-10} Pa was obtained in the a main track line chamber and the pressure increased to 2.0×10^{-9} Pa after opening the gate valve between the main track and the connected instrument chamber. A sample could be transferred from a hoist stage in the connecting chamber for the sidetrack chamber to the other in the main chamber within the pressure of 10^{-11} Pa. This indicates that the current system is successful in the transport in near XHV pressure range but that additional improvement of the system is required for the stable transport in XHV.

Conclusion

The surface of hexagonal boron nitride was found to have little attractive force and can be good substrate for van der Waals' epitaxy for nano scale structure fabrication. Low temperature fabrication of h-BN film could be

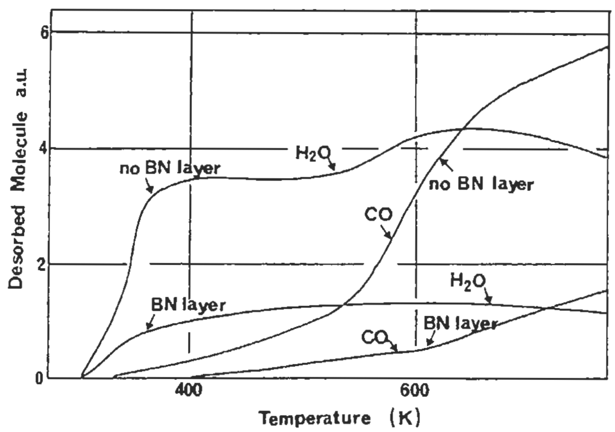

Fig.4 CO and H_2O TDS spectra.

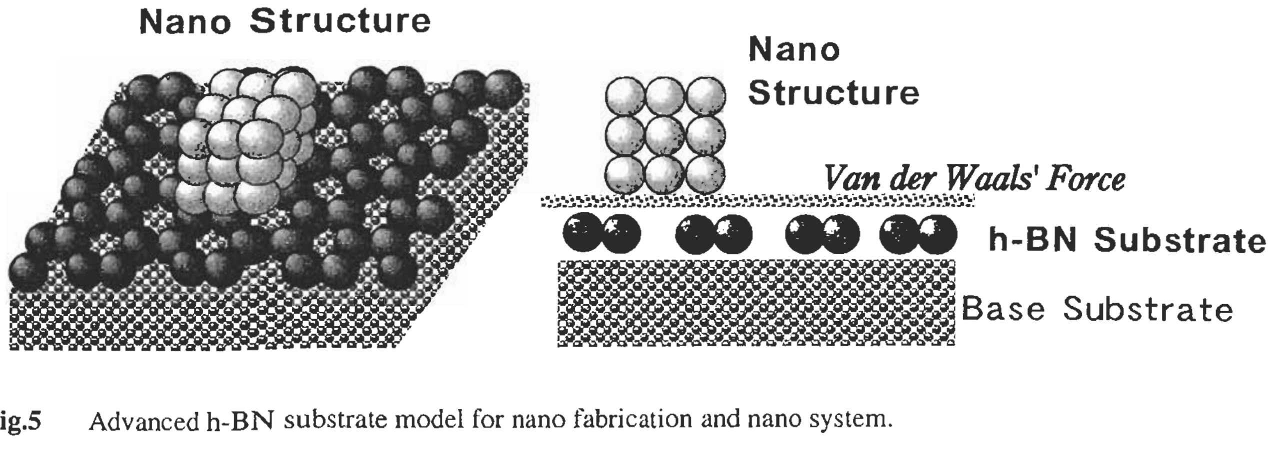

Fig.5 Advanced h-BN substrate model for nano fabrication and nano system.

obtained using co-sputtered film surface segregation method with helicon sputtering deposition.

The XHV integrated process was developed for the atomic scale fabrication of nano structure of quantum material. The pressure change less than 10^{-11} Pa was successfully acquired during the sample transfer operation in the integrated process due to the levitation transfer systems.

We are completing the first phase of the project to construct the XHV integrated process and have started the second phase to prepare the layered thin film substrate using surface segregation of hexagonal BN for van der Waals' epitaxy for nano structure fabrication and nano system.

References

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