Soft X-ray Reflectivity Measurements of Amorphous Carbon Thin Films Using Indus-I

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Abstract

Using Indus-I synchrotron radiation source, the soft x-ray reflectivity measurements have been performed on electron beam deposited amorphous carbon thin film. The study shows that soft x-ray reflectivity is an extremely effective, accurate and non-destructive technique for measuring thickness, density, and microscopic roughness. High q- space resolution at larger wavelength permits to investigate thicker films in the range of 100 to 3000Å. Our simulation study for hard x-ray region reveals that the instrumental resolution factor limits the probing thickness range.

INTRODUCTION:

In the last few years, studies on amorphous carbon (a-C) and carbon based thin films have been extensively reported [1-4]. These films find wide applications in micro electronic devices, due to their important electrical and mechanical properties. Fabrication of various electronic devices made of a-C films viz. Schottkey diodes, metal insulator semiconductor diodes, and hetrojunctions with silicon have been reported [1]. Amorphous carbon films show a wide energy band gap, and have been used as window layer in hydrogenated amorphous silicon based solar cells, for the enhancement of open circuit voltage and for improving the short wavelength response. Thin films of a-C are ideal protective coating for magnetic and optical disks.

Ultra thin carbon films are important spacer layer of nano meter period multilayer structures. These structures find extensive application as x-ray optical elements. Thermal stability of carbon based multilayers is important for use in synchrotron beam line applications, where considerable heating can occur [5,6].

Measurements of thickness, density, microscopic surface roughness of a-C and carbon based thin films have been extensively reported using hard x-ray reflectivity (XRR) measurements but soft x-ray reflectivity (SXR) studies are rather scares [1-8]. XRR allows one to probe electron density profile over length scales of few tens of Å (Bragg diffraction in multilayers) to several hundred Å (small angle x-ray scattering). It is difficult to obtain structural information in the range of 500-3000Å, due to limited q-space resolution in XRR studies. Utilizing long wavelength, soft x-ray radiation, the scattering angles are increased, leading to higher q-space resolution. However, increased absorption at soft x-ray wavelengths, led to almost complete neglect of this wavelength region. In order to carry out structural studies in thin films and multilayer, we have constructed a soft x-ray/ extreme ultra violet reflectometer [7]. Angle dependent soft x-ray reflectivity ($R - \theta$) at various wavelength in the range of 50-100Å were measured using a high precision reflectometer station on bending magnet CAT-TGM beamline.

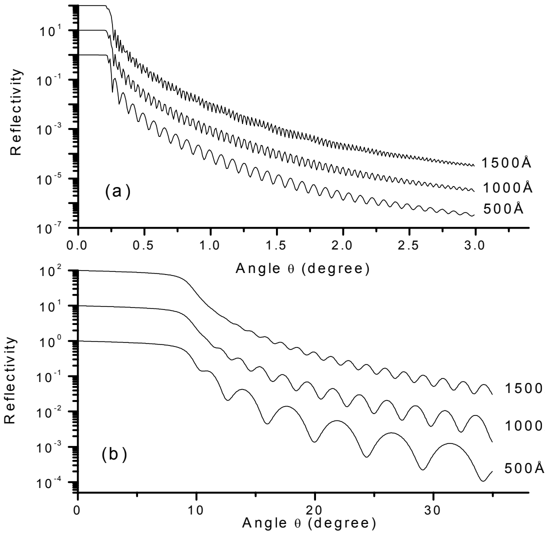

Figure1:(a) Simulated hard x-ray reflectivity spectra of carbon film with various thickness at λ=1.54Å. The data are convoluted with 0.01° of gaussian beam width, (b) simulated soft x-ray spectra for λ=80Å, with beam divergence of 0.15°.

We report here studies on electron beam deposited a-C thin films, with specific purpose of measuring film density, thickness, rms roughness. Carbon films on float glass substrate were prepared by electron beam evaporation of graphite target. Electron beam deposition is a low energy process (~3000ºK, kT~0.3eV), thus C films are amorphous and non-diamond like.

The ($R - \theta$) curve was fitted by stratified layer formalism of Parratt [9]. Nevot-Croce [10] model was used to incorporate the surface and interface roughnesses in layered system with infinitely absorbing substrate.

RESULTS AND DISCUSSIONS:

Figure 1(a) shows calculated reflectivity spectra of carbon thin film for various thicknesses at λ=1.54Å. The oscillation in spectra arises due to interference between

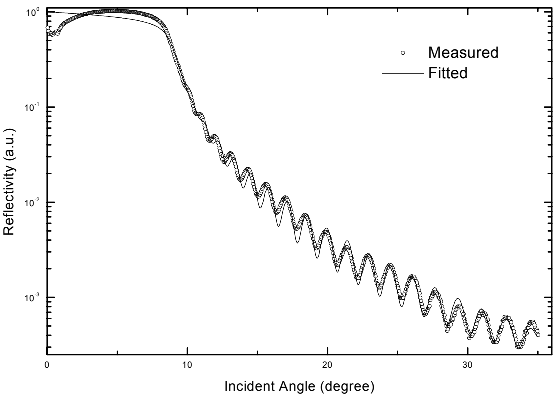

Figure 2: Measured soft x-ray reflectivity spectra of 1500 Å thick carbon film at λ=80Å. Measured and fitted spectra are represented by open circle and continuous line respectively.

light reflected from vacuum/film interface and film/substrate interface. With increase in film thickness, the frequency of oscillations increases. The simulation results show that for typical beam divergence of 0.01°, the oscillations for film thicker than 1000Å cannot be resolved. Theoretical limit of maximum detectable film thickness, for a given measurement, depends upon beam divergence ($t_{\max} = 2\pi/\Delta q$, where Δq is the momentum resolution factor). To measure thick films using XRR, one needs to have extremely low beam divergence, and high-resolution angular movement. Figure1(b) shows the calculated reflectivity spectra for carbon film with various thicknesses at λ=80Å. The results suggest that the oscillation fringes are quite wide even for 1500Å thick film. The separation between two minima is ~0.5°, which can easily be detected with normal precision and angular resolution. With increase in wavelength, the Δq resolution of measurement system increases. The increase in absorption factor for soft x-ray region limits the $t_{\max}$ value.

The measured SXR spectrum (λ=80Å) of 1500Å thick carbon film deposited on float glass substrate is shown in Figure2. The open circle shows measured curve whereas the continuous line represents fitted curve. The beam divergence, in the present measurement was 0.15°. Fitting result reveals that the film thickness is 1493Å. The roughness of vacuum/film interface is 3.8Å. The density of the film comes out to be 92% of bulk value.

Similarly the SXR measurements of 350Å thick carbon film measured at various wavelengths are shown in Figure3. From fitting the thickness of film comes out to be 332Å. The density of the film is 90% of the bulk. All fitting parameters are found to be consistent at different wavelengths. However the large disagreement between fitted and measured spectra for λ=60Å is due to scattering background. The considerable efforts are underway to reduce the scattered noise at lower wavelength side by introducing beam apertures at various positions in beamline.

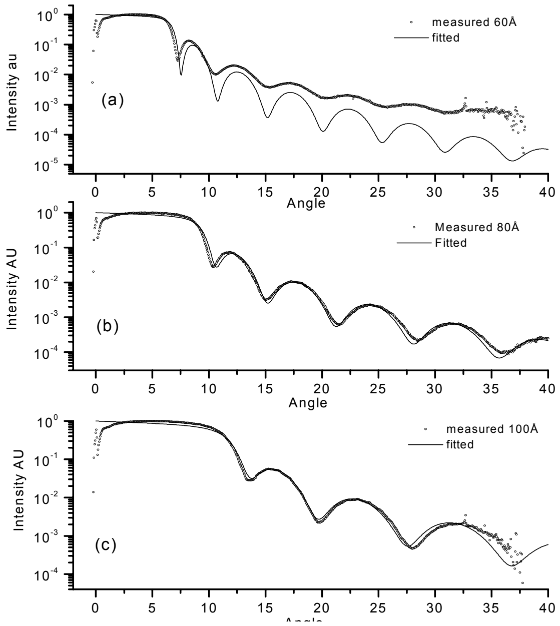

Figure 3: SXR spectra of 350Å thick carbon film measured at various wavelengths (a) 60Å, (b) 80Å and (c) 100Å.

Using CAT-TGM beam line on Indus-I synchrotron source, the precision reflectivity measurements of carbon films are carried out. Thicker films of low Z materials can easily be studied using soft x-ray radiation. Good quality reflectivity profiles are limited to a lower wavelength limit of 50 Å, due to higher scattering from the optical components and beam pipe. Efforts are underway to reduce the scattering by introducing apertures at various positions in the beamline and just before the sample.

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