Novel Multilayer Reflectors for "Water-Window" Wavelengths Fabricated by Atomic Layer Deposition/Epitaxy

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Since Barbee, Jr. et. al. demonstrated successfully normal-incidence soft-X-ray reflectors with high reflectances over 50% at 13.8 nm by means of 50-layer Mo/Si multilayers deposited by a magnetron sputtering, there have been various fabrication studies on soft-X-ray multilayer reflectors using electron beam evaporation, and ion beam, RF and DC magnetron sputtering depositions. Especially, development of high-performance normal-incidence multilayer optics for the so-called water-window wavelength region between the oxygen and carbon K absorption edges at 2.33 and 4.36 nm, respectively, which has been a target of the lasing wavelength in soft-X-ray lasers, is one of challenges to modern technology.

We have proposed novel multilayers for soft-X-ray reflectors at water-window wavelengths, fabricated by atomic layer deposition / atomic layer epitaxy technique. Here, two topics as follow will be reviewed.

(1) Novel Oxide Multilayer Reflectors by Atomic Layer Deposition / Epitaxy.1,2)

We have proposed the use of a novel metal oxide multilayer for soft-X-ray reflectors at water-window wavelengths, because an oxide multilayer can prevent the formation of an alloy at the interface, and the absorption of oxygen in oxides is negligible at the water-window wavelengths; moreover, the metal oxide multilayer can be fabricated by the atomic layer deposition or atomic layer epitaxy technique. These techniques can be used to control surfaces on an atomic scale by sequentially dosing the surface with appropriate chemical precursors and then promoting surface chemical reactions which are inherently self-limiting. We have found that the self-limiting adsorption mechanism works in the fabrication of oxide thin films such as aluminum oxide and titanium oxide.

20 bilayers of titanium oxide and aluminum oxide with the layer-pair thickness of 4.43 nm on a silicon substrate were fabricated for novel multilayer reflectors at water-window wavelengths by an atomic layer deposition method of controlled growth with sequential surface chemical reactions. The high reflectance of over 30% at a wavelength of 2.734 nm and an incident angle of 71.8 deg. from the normal incidence was demonstrated experimentally. The full width at half-maximum of the reflectances at 2.734 nm was 0.0381 nm, which corresponds to delta(lambda)/lambda = 1.4%.

Atomic layer epitaxy of oxide thin films for multilayer reflectors with superlattice structures was also investigated. Details will be introduced in our presentation.

(2) Multilayer Reflectors by Layer-by-Layer Growth and Multi-Periodic Structures3,4)

In atomic layer epitaxy, source gases are alternatively introduced into the growth chamber, and due to a 'self-limiting mechanism', the epitaxial growth is automatically stopped after 1 monolayer with each alternative gas supply phase, thus atomic layer epitaxy has great potential for the realization of the short period multilayer structures with atomically abrupt interfaces. However multilayer mirrors fabricated by atomic layer epitaxy have discrete reflection wavelength, since the periodic length is discrete according to the layer-by-layer growth. Here, we introduce a new wavelength control method using a multi-periodic structure, which enables us to design the X-ray mirror with a selectable reflection wavelength by a combination of layer-by-layer growth of films with various periodic lengths. In addition to this theoretical prediction of multi-periodic mirrors, we have made normal X-ray multilayer mirrors in order to investigate X-ray properties of layer-by-layer grown films.

The reflection wavelength of the multi-periodic structure is determined by the combined ratio of periodic layers. The X-ray phase at the reflection wavelength is compensated, and the X-ray loss by this compensation is quite low. Multi-periodic structures fabricated by atomic layer epitaxy are expected to act as short wavelength X-ray mirrors without interface roughness.

In order to investigate X-ray properties of layer-by-layer grown films, normal X-ray multilayer mirrors are made by atomic layer epitaxy. By virtue of the atomic order thickness controllability of atomic layer epitaxy, the reflection wavelength can be controlled with high precision.

References

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