Si 基板上への Si/Gd_2O_3 ヘテロ構造の MBE 成長

MBE growth of Si/Gd_2O_3 heterostructure on Si substrates

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Single crystalline Er-doped rare earth oxides (REO) are appealing solid-state materials for the realization of optical quantum memories in the telecommunication band [1,2]. In order to realize these devices, a high-quality rare-earth oxide crystal and a following implementation of a basic waveguide structure with large overlap between light and REO are desirable. Recently we have successfully grown a-Si/Gd_2O_3 horizontal-slot-waveguides on SOI substrates by molecular beam epitaxy (MBE) using molecular oxygen (O_2) as an oxygen precursor [3]. However, some important problems that should be settled were left; those are very slow growth rate of Gd_2O_3 (< 20 nm/h) and uniformity of refractive index of Si cap layer grown on Gd_2O_3. In this paper, we examine new growth method of Gd_2O_3 with faster growth rate and Si cap with single crystal phase on it.

Gd_2O_3 and Si cap layers were grown by MBE on Si or SOI (111) substrates. In order to obtain faster growth rate of Gd_2O_3, we used oxygen radical (O*) with stronger oxidizability in substitution for O_2 molecules. After the optimization of growth condition (growth temperature, flux ratio of Gd/O* and so on), we obtained the Gd_2O_3 layers with 2D growth mode as shown in Fig.1. In this case the growth rate and surface roughness are about 100 nm/h and 0.3 nm, respectively. These results indicate that the Gd_2O_3 growth with O* is effective both for obtaining higher growth rate and maintaining crystal quality. Single crystalline Si cap layers were also grown on this Gd_2O_3 surface with various growth conditions. However, epitaxial 2D growth of Si on Gd_2O_3 cannot achieved straightforward (Fig.2), because usually the (111) surface energy of rare earth-oxides is about two times lower than those of Si (γ_{Gd2O3} = 500 -700 mJ/m^2, γ_{Si} = ~1500 mJ/m^2) [4]. That means Si does not wet Gd_2O_3. Considering this evidence, the a-Si layer is more suitable for the Si cap on Gd_2O_3 rather than the epitaxial Si layer.

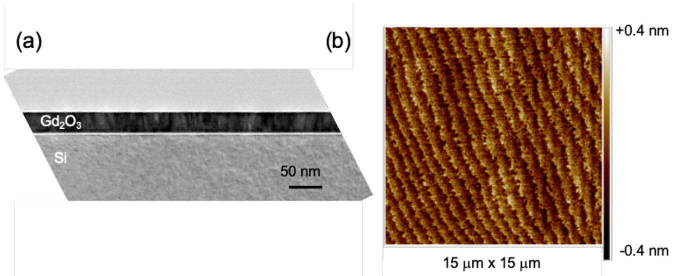

Fig.1 (a) Cross-sectional TEM image and (b) surface AFM image of grown Gd_2O_3 with O*.

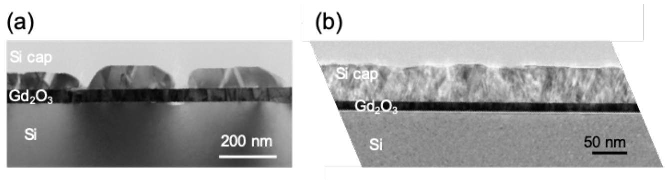

Fig.2 Cross-sectional TEM image of Si/Gd_2O_3 heterostructures with different growth condition.

The resultant heterostructure of the a-$Si/Gd_2O_3/Si$ must be promising for a following doping with Er ions and for the realization of an optical waveguide in rare earth doped oxides.

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