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Engineering of Interface Between Silicon and Rare-Earth-Oxide Buffer for GaN growth

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Efforts to mitigate stress in III-N semiconductor layers grown on Si(111) and prevent excessive bow of the wafers and even cracking of the layers have lead to introduction of variety of materials for buffer between the layer and the substrate. Growth of GaN on rare-earth oxides (REO) and stress reduction in the heterostructures was demonstrated already [1,2]. Among these, erbium oxide with superior kinetic and thermal stability at typical III-N metal organic chemical vapor deposition process temperatures is of particular interest. On the other hand, gadolinium oxide lattice mismatch to silicon is very low. However, Gd_2O_3 crystal structure may transform from cubic bixbyite to monoclinic at high temperatures. Combination of those two materials opens opportunity for growth of multilayer buffer for growth of III-N materials. In this work, we present results of engineering on an interface between REOs (Er_2O_3 and Gd_2O_3) and silicon substrate and demonstrate its influence on structure of the oxide layer as well as GaN layer grown on the top of it. An epitaxial REO layer is coupled very strongly to silicon substrate via high ionic RE-O-Si bonds and its lattice is tetragonally distorted due to difference in thermal expansion coefficient [3]. Additionally, difference in lattice spacing between the oxide and silicon leads to stress that during growth of the layer gradually relaxes by forming dislocations, roughening of the oxide surface. The dislocations propagate to the surface of the oxide and nucleate there in shape of hillocks, density of the defects on the layer surface correlates with lattice mismatch to the substrate and the layer thickness. Attempts to reduce lattice mismatch between erbium oxide and silicon substrate by growth of almost fully relaxed gadolinium oxide layer prevents formation of the dislocations in the oxide layer and subsequently hillocks on its surface. However, lack of the stress relaxation sites leads to cracking of the layer after reaching its critical thickness. One of the ways to reduce the stress in the layer is its crystallographic decoupling from the substrate by forming amorphous interface layer between the two. Reduced viscosity of SiO_2 at temperatures higher than 500°C helps for relaxation of the stress not in an epitaxial layer but in the amorphous interlayer. However, attempts of direct growth of an epitaxial rare-earth oxide on oxidized silicon surface result in very poor crystal quality of the oxide due to lack of crystallographic register from the Si substrate to the rare-earth oxide layer. We present patented method [4] for formation of amorphous silicon dioxide layer. Silicon oxidation is diffusion limited process, but REOs distinguish themselves by high oxygen diffusion. In order to enhance oxidation of the interface and to form thicker silica layer, silicide-like interface between the oxide and the silicon was formed by initial growth at oxygen deficient conditions. After initial growth of a REO layer with thickness of several nanometers, the process is stopped and the layer is annealed at 900°C in oxide ambience in the growth chamber for 60 minutes. Later, the growth is continued at optimized rare-earth oxide epitaxy conditions [3]. Typical for rare-earth oxides bixbyite structure streaky reflection high energy electron diffraction (RHEED) pattern with minimal intensity modulation along the diffraction maxima reveals high crystal quality of the grown layer. Transmission electron microscopy (TEM) study of a gadolinium oxide layer on Si(111) reveals that the silicide-like interface between the silicon and the oxide transforms to silicon dioxide and rare-earth silicate layers (Fig. 1). Atomic force microscopy (AFM) analysis of 500 nm thick erbium oxide layer grown with and without the silicon dioxide interlayer confirms improvement of the surface morphology in the former case. Additionally, morphology of two samples with 150 nm thick erbium oxide layer grown on 30 nm thick gadolinium oxide was compared using AFM. The sample without any interlayer between the gadolinium oxide and silicon is cracked (in Fig. 3a cracks are marked with white arrows). The surface of the sample with SiO_x interlayer between Gd_2O_3 and Si shows no cracks (Fig. 3b).

Fig. 1 RHEED pattern in (110) azimuth of Gd_2O_3 grown on Si(111) via SiO_x interface layer.

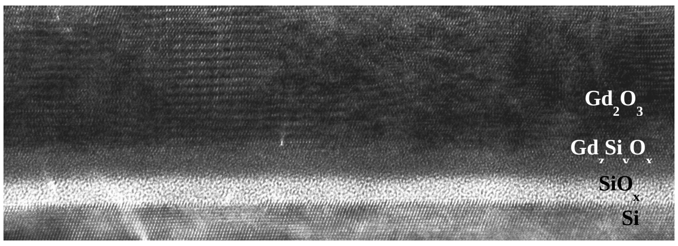
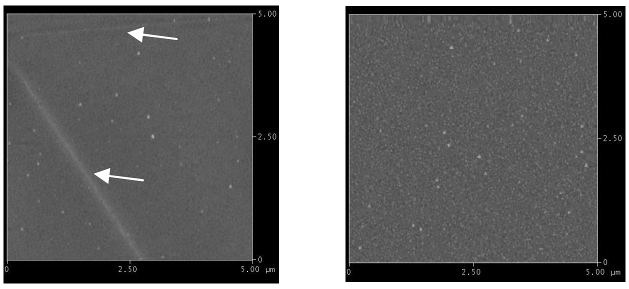


Fig. 2 The structure with crystalline Gd_2O_3 layer grown via amorphous SiO_x interlayer on Si (111) substrate.



a) b)

Fig. 3. 5µm x 5µm AFM scan of 150 nm Er_2O_3 layer grown on 30 nm Gd_2O_3 layer on Si(111) without any interlayer (a) and with SiO_x interlayer between Gd_2O_3 and Si (b).

References:
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