566a Controlled Doping in Ultra-Thin Metal Oxide Films by Radical-Enhanced Ald

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In this work, we demonstrated radical-enhanced atomic layer deposition (RE-ALD) as an ideal technique for incorporation of dopants in ultra-thin metal oxide films. The controlled doping of erbium in yttrium oxide is presented as a case study. Er-doped Y_2O_3 thin film is a potential waveguide core material for planar miniature optical amplifiers. Though SiO_2 has traditionally been used as the host material for Er ions in fiber amplifiers (~20 meters long), it is an unsuitable host in small, compact amplifiers due to its low solubility for erbium. In contrast, Y_2O_3 has a similar crystal structure and lattice constant as Er_2O_3, which in principle allows for a much higher concentration of Er to be incorporated, and hence higher gain values. The metal ß-diketonates, $Y(TMHD)_3$ and $Er(TMHD)_3$, were used as the metal precursors and O radicals as the oxidant. The study of surface reaction kinetics in-situ using a quartz crystal microbalance (QCM) confirmed the self-limiting surface reactions in depositing pure Y_2O_3 and Er_2O_3. Specifically, adsorption of the precursors was found to follow the Langmuir adsorption model. The O radicals not only create reactive sites for precursor adsorption but also effectively remove the ß-diketonate ligands. Conformal deposition of stoichiometric and smooth metal oxide thin films with minimal carbon contamination was achieved at 300-330°C, confirmed by X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), and scanning electron microscopy (SEM). Er-doped Y_2O_3thin films were synthesized by depositing Y_2O_3 and Er_2O_3 in an alternating fashion at 350°C. Specifically, the erbium doping level was effectively controlled by varying the ratio of Y_2O_3:Er_2O_3 cycles during deposition, and a 20:1 ratio yielded ~6 at.% Er in Y_2O_3. At 350°C, the films were found to be polycrystalline showing a preferential growth direction in the (111) plane. Room-temperature PL at 1.54 µm characteristic of the Er intra 4f transition was observed in a 500-Å Er-doped (6.6 at.%) Y_2O_3 film deposited at 350°C. Well resolved Stark features indicated proper incorporation of Er in the Y_2O_3 host. The result is very promising, since the film is fairly thin and no annealing at high temperature is needed to activate the erbium ions. This suggested that radical-enhanced ALD was able to preserve the optically active trivalent state of the erbium ion from its precursor state. Significant PL quenching was observed in thin films incorporated with more than 12 at.% Er. Extended X-ray absorption fine structure (EXAFS) analysis showed an identical Er local environment in samples with 6-14% of Er, suggesting that the PL quenching observed at high Er concentration (>12 at.%) is likely dominated by ion-ion interaction and not by clustering. The effective absorption cross section for Er^{3+} ions incorporated in Y_2O_3 was determined to be ~ $10^{-18}cm^2$, about three orders of magnitude larger than the direct optical absorption cross section reported for Er^{3+} ions in a stoichiometric SiO_2 host. These results validate Y_2O_3 as a promising Er host material and demonstrate that RE-ALD is a viable technique for synthesizing thin films with well-controlled dopant incorporation. Fabrication of planar optical amplifiers is currently underway to determine the fraction of optically active Er^{3+} in Y_2O_3 and also the optical gain values for these devices.