[IV-21] [초청]

Room temperature 1.54 μm Er^{3+} luminescence from erbium doped oxygen-rich silicon deposited by electron cyclotron resonance plasma enhanced vapor deposition.

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Erbium, when incorporated into a suitable host matrix, luminesces near 1.54 μm, corresponding to an intra-4f shell transition from the first excited ($^4I_{13/2}$) to the ground state ($^4I_{15/2}$). As an optical dopant in silicon, it offers the exciting possibility of bringing the vast silicon integrated circuit technology into optoelectronics. Since the initial study, the research has progressed to a point where room temperature electroluminescence of erbium has been reported in both crystalline and amorphous silicon[1].

For efficient luminescence, direct deposition of erbium doped films (as opposed to implantation) is highly desired. This is especially true for erbium doped amorphous silicon, which cannot tolerate high temperatures needed to anneal out implantation damage. Here we report on the development of a new method of depositing erbium-doped silicon films, and the photoluminescence properties of such films.

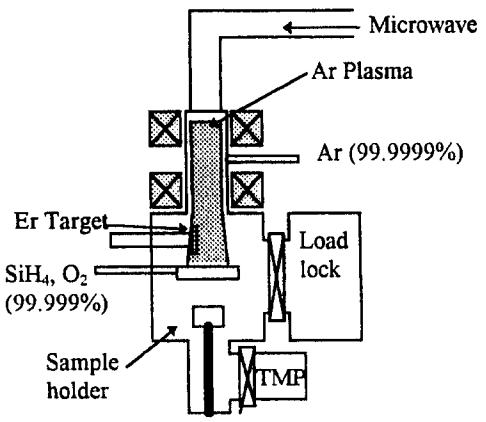

Figure 1: Schematic of deposition chamber

Figure 1 on the left shows the schematic of the deposition chamber. Argon plasma is generated in the ECR chamber, and silane and oxygen gases are introduced downstream to be ionized deposited. A solid erbium target is inserted into Ar plasma, and biased to -200 V. This results in sputtering of erbium by Ar ions, doping the silicon film with erbium. The deposition temperature was 300 °C; the deposition pressure was 7×10^{-5} torr; and the erbium target current was 40 mA for all samples. The silane/oxygen flow ratio was varied from 3:1 to 1:3. All samples had a nominal thickness of 500 nm. Some samples were rapid thermal annealed in flowing Ar atmosphere for 7.5 min at 500, 700, and 900 °C. Photoluminescence (PL) spectra were measured at room temperature using Ar laser as the excitation source, and a Ge detector that was also at room temperature without lock-in or other noise reduction technique. Photoluminescence excitation spectroscopy was performed using the different lines of Ar laser (455nm-515 nm range).

As deposited samples are amorphous. However, they develop crystalline structure after 900 °C anneal. As shown in Fig. 2, strong room-temperature Er^{3+} luminescence is observed. Figure 3 shows the dependence of Er^{3+} luminescence intensity upon annealing. For silicon-rich samples, 1.54 μm Er^{3+} luminescence in most intense as-deposited, and high temperature anneal quenches the luminescence intensity. On the other hand, oxygen-rich samples display Er^{3+} luminescence only after high temperature annealing. The most intense Er^{3+} luminescence is observed for SiH_4:O_2 flow ratio of 1:1, after 900 °C anneal.

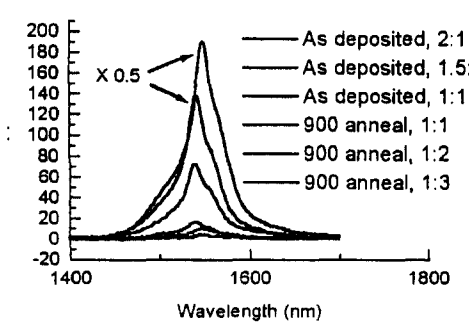

Figure 2: PL spectrum

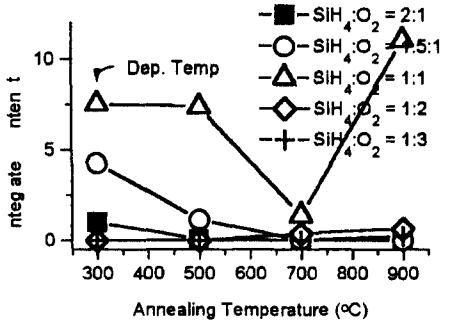

Figure 3: PL intensity vs T_{anneal}

Figs. 4 and 5 show the Er^{3+} luminescence intensity as a function of the excitation wavelength. PL intensities from oxygen-rich samples show peaks at 488 and 515 nm, coinciding with optical absorption bands of Er^{3+}, showing that excitation is dominated by direct absorption of photons (SiO_2-like matrix). PL intensity from silicon-rich samples do not show such peaks, showing that the excitation is dominated by carrier recombination (semi-conducting host matrix), which is far more efficient that direct optical absorption.

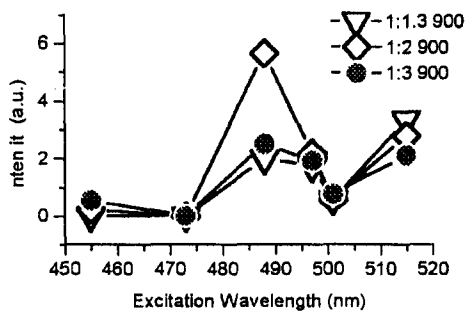

Figure 2: Oxygen-rich samples

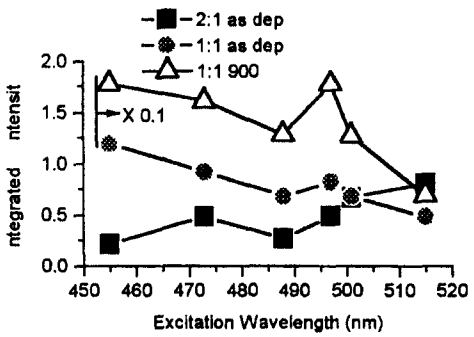

Figure 3: Silicon-rich samples

This difference in the excitation mechanism can be used to understand the dependence of luminescence intensity on the annealing temperature. For oxygen-rich samples, annealing increases the Er^{3+} luminescence intensity by optically activating erbium atoms and by forming a defect-free SiO_2 matrix. For silicon-rich samples, however, annealing removes hydrogen atoms which passivate the defects, and thus decreases the carrier lifetime, resulting in lower excitation efficiency. We believe that the sample with SiH_4:O_2 flow ratio of 1:1 luminesces intensely after anneal because it has enough oxygen atoms to passivate all the defects, but not too many that the carrier recombination still dominates the excitation process. Such argument is supported by the fact that the sample with SiH_4:O_2 flow ratio of 1:1.3 shows visible luminescence typical of silicon nanoclusters, showing that silicon clusters in such a matrix are well-passivated.

In conclusion, we have observed room temperature Er^{3+} luminescence from Er-doped oxygen-rich silicon. Defect passivation, either by hydrogen or annealing, is the key issue in determining luminescence efficiency. Highest luminescence intensity is observed for SiH_4:O_2 ratio of 1:1.

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[1] See, for example, *Rare Earth Doped Semiconductors*, MRS Symp. Proc. Vol 422 (1996)