Photoluminescence from magnetron-sputtered SiO_2 films co-doped with (Er, Ge) under excitation of a 325 nm He-Cd laser line

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Introduction

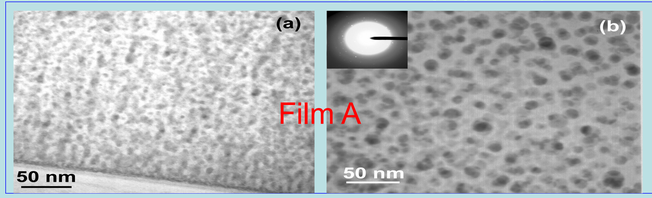
- Er-doped Si-rich Si oxide has been studied intensively for the development of light sources or optical amplifiers at ~1.54 μm in telecommunications, as well as the red, green and blue for display applications [1].
- The emissions from Ge nanoclusters (Ge-ncls) and/or Ge-related defects are quite different, which may result in different luminescence properties when co-doped with Er ions [2].
- In a previous study, we have reported the PL from an (Er, Ge) co-doped SiO_2 film excited by a 488 nm Ar-ion laser line, and found that the Er PL intensity was strongest after annealing the film at 700 ° C in N_2 for 30 minutes [3].
- The 488 nm excitation wavelength is resonant with the Er^{3+} $^4F_{7/2}$ energy level, direct excitation of Er^{3+} by the laser line is not negligible.
- In this work, we report the PL properties of SiO_2 films co-doped with (Er, Ge) under the non-resonant excitation of a 325 nm He-Cd laser line, and study the effects of Er concentrations on the Er PL.

Experimental details

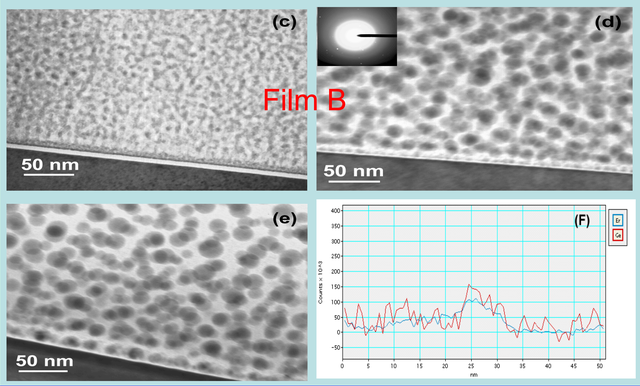
- The (Er, Ge) co-doped SiO_2 films (A and B) were deposited on Si substrate by magnetron sputtering an Er+Ge+SiO_2 composite target. Two control films (Er+SiO_2 and Ge+SiO_2) were also deposited under the identical conditions.
- The Ge and Er concentrations in film A are 7.4 at.% and 1.3 at.% respectively; while in film B are 7.0 at.% and 2.82 at.% obtained by Rutherford backscattering spectroscopy.
- All the films were annealed in N_2 for 30 minutes at the temperatures indicated in the figures.
- Transmission electron microscopy observation was performed by using a Philips CM12 microscope operating at 120 keV, and a JOEL 2010F microscope operating at 200 keV.
- PL: Excitation: 325 nm line of a He-Cd laser
  Detection: Spectrometer with a CCD array for "Visible" (350-950 nm) PL.
  Monochromator with a Lock-in amplifier (40 Hz), InGaAs detector for Er^{3+} 1.54 μm PL.

Experimental results and discussions

1, The precipitation of amorphous (a-) or crystalline (c-) Ge-ncls

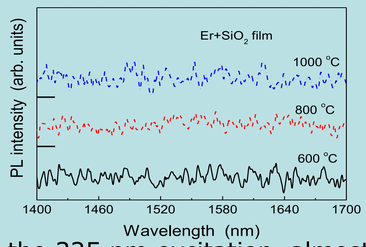


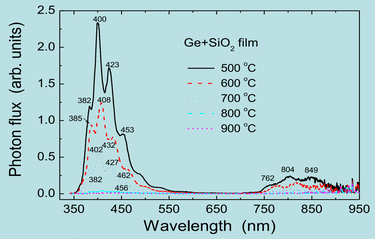
- Fig. (a) after 625 ° C anneal, a-Ge-ncls have precipitated with average size of 4-5 nm;
- Fig. (b) after 850 ° C anneal, c-Ge-ncls form with average size of 11 nm.



- Fig. (c) after 500 ° C anneal, a-Ge-ncls have average size of ~ 4 nm;
- Fig. (d) after 800 ° C anneal, c-Ge-ncls have average size of 14.3 nm;
- Fig. (e) after 900 ° C anneal, the size has increased to be 15.9 nm;
- Fig. (f) the electron energy loss spectra for line-scanning across a Ge-ncl indicates the distributions of Ge and Er are highly correlated.

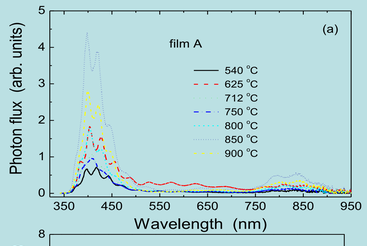
2, The photoluminescence from Er+SiO_2 film and Ge+SiO_2 film

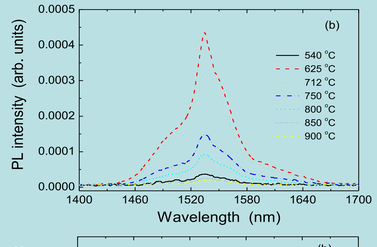


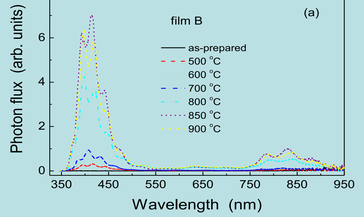


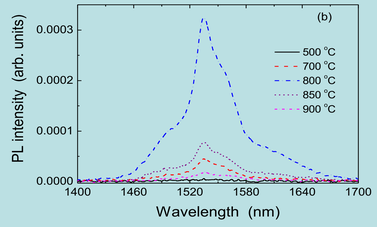
- Under the 325 nm excitation, almost no direct excitation of Er^{3+} was observed in the Er doped SiO_2 film;
- Strong blue (~ 400 nm) and near infrared (~ 800 nm) emissions were observed from the Ge doped SiO_2 film, which are attributed to Ge-related defects and Ge-ncls, respectively; the peaks superimposed on the blue and near-infrared bands are believed to be due to multiple interference effects on the reflectivity.

3, The photoluminescence from films A and B









- The PL spectra from the films A and B show different annealing behaviors with increasing annealing temperature, which should be related to different Er concentration in the films;
- The strongest "visible" PL intensity from the film B is one time stronger than that from film A, but the Er PL intensity of film B has not evidently improved.

Conclusions

- Under the excitation of a 325 nm laser line, strong blue emission at ~ 400 nm and near infrared at ~ 800 nm were observed from the films, which are attributed to Ge-related defects and Ge-ncls, respectively. Strong Er^{3+} PL near 1.54 μm were also observed.
- Almost no direct excitation of Er^{3+} was observed from Er-doped SiO_2 film; the pronounced Er PL in the films A and B should be due to the incorporation of Ge.
- The results suggest that the excitation of the Er ions is mainly a Ge-ncl-mediated energy transfer process. However, we do not rule out defect-mediated excitation.

References

1. See for examples: A. J. Kenyon, et al, J. Phys.: Condens. Matter. **6**, L319 (1994); A. Polman, J. Appl. Phys. **82,** 1 (1997); A. Polman et.al, J. Opt. Soc. Am. B **21**, 871 (2004).
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Acknowledgments

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