Low-Energy Ion-Beam-Assisted Sputtering for Si Nanocrystals

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This work reports the low-energy ion-beam assisted sputtering (IBAS) for synthesis of the Si-rich oxide (SRO) films. The ion beams provided additional energy for the species to form crystallinic bonding and to crack the large radical in plasma. The IBAS effectively increased the density of Si NCs and lowered the required annealing temperature. Additionally, the IBAS showed capability to modulate the size and density of Si nanocrystals (NCs) in SRO films. Room-temperature photoluminescence for the un-annealed SRO films that was prepared by the IBAS was observed. The annealing increased the PL intensity and the emission wavelength. The SRO films that were prepared by sputtering and IBAS were compared, and the corresponding material and optical properties were investigated. Finally, we suggest the proposed method will be useful for future development of Si NCs.

**Fig. 1** Schematic diagram of the IBAS system.

**Fig. 2** Size and density Si NCs in SRO films by sputtering and IBAS.

**Fig. 3** PL spectra of IBAS (40V) SRO films before and after annealing.

**Fig. 4** TEM images of the SRO layer prepared by sputtering (a), and IBAS with ion beam voltages (b) 20V (c) 40V (d) 66V. All samples were annealed at 1000°C for 3h.

**Fig. 5** XPS of Si 2p signal of the SRO films before and after annealing: (a) sputtering (0 V), (b) IBAS (20 V), (c) 40V, (d) 66V.

**Conclusion**

- The SRO films prepared by IBAS showed denser and larger Si NCs than those prepared by sputtering as the anode voltage increased from 0 to 40 V. The size and density decreased when the anode voltage exceeded 40 V.
- The annealing increased the $S_{0}^{+} / S_{4}^{+}$ ratio for samples that were prepared by IBAS; while the annealing decreased the $S_{0}^{+} / S_{4}^{+}$ ratio for those prepared by sputtering.
- The IBAS provided additional energy and lowered the barrier to form the Si NCs, reducing the required annealing temperature.
- The PL signal of the un-annealed sample was observed. Intensity of PL signal was increased, and the peak was blue-shifted (~45nm) after annealing, indicating the formation and coarsen of the Si NCs.