X-ray Microprobe Diagnostics for Photonic Device Development and Manufacturing

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Introduction

The properties of the amorphous SiO_2-based materials used in optical devices vary tremendously with the introduction of impurities. For example, a spatially varying concentration of impurities, such as P, B, or Ge, that raise the index of refraction can be used to create optical waveguide structures in fibers or in planar devices. Similarly, the controlled introduction of rare-earth impurities can be used to build optical amplifiers. In both cases optimizing the operation of devices depends on controlling the micron-scale distribution of these atoms. We have studied the composition of optical devices at this length scale by mapping elemntal x-ray fluorescence excited with an x-ray microprobe.

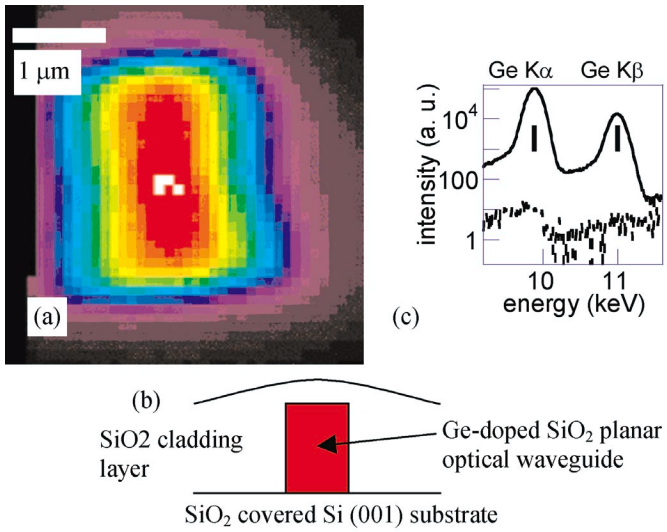

FIG. 1. (a) A map of the intensity of the Ge Kα fluorescence from the planar waveguide structure for which the cross section is shown schematically in part (b). The color scale ranges from black (least intense) to white (most intense). (c) The energy spectrum of fluorescence in the energy region of Ge Kα and Kβ characteristic radiation with the beam illuminating the doped region (solid line) and the oxide cladding layer beneath it (dashed line).

Method

Radiation from the one-crystal monochromator at the side-branch beamline 2-ID-E was focused using a Fresnel zone plate. In studies of Ge-doped planar waveguide structures, we used 13 keV incident radiation in order to obtain fluorescence from the Ge K lines. For rare-earth doped fibers the incident energy was 9.8 keV. The focal spot in both cases was approximately 0.5 μm in diameter. As the sample was scanned under the beam, the characteristic fluorescence of dopant atoms was collected with a three-element lithium-drifted Ge detector. We thinned the samples to 6 ± 2 μm prior to the measurement to reduce the contribution of elastically scattered photons to the signal at the detector and to mitigate the effects of a small misalignment of the sample normal and the incident beam.

Results and Discussion

A map of the intensity of Ge Kα fluorescence—as a Ge-doped planar waveguide structure was scanned under the focused beam—is shown in Fig. 1a. The structure consisted of a highly Ge-doped SiO_2 film on an SiO_2-covered Si substrate. The Ge film had been patterned to form a ridge and was overcoated with a second SiO_2 layer, forming an optical waveguide. The area in which the Ge fluorescence intensity exceeded half its maximum value was 1.8 μm wide and extended 2.5 μm along the growth direction of the film. This is in excellent agreement with the size determined by scanning electron microscopy. We are actively seeking a correlation between the distribution of Ge within the waveguide structure and the device performance that may lead to improvements in device-processing techniques. In similar measurements with cross sections of fibers used in optical amplifiers, we have measured the distribution of Er and Yb dopant atoms with a similar goal.

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Reference

[1] Y.P. Li, C.H. Henry, in *Optical Fiber Telecommunications*, Vol. IIIB, I. P. Kamimow, T. L. Koch, eds. (Academic Press, New York, 1997), pp. 319-376.