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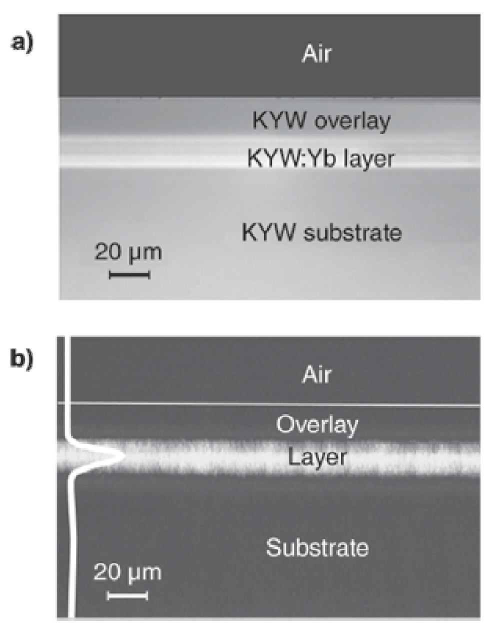
Waveguide Laser: Yb-doped waveguide lases near 1 µm

For what they believe to be the first time, researchers at the Ecole Polytechnique Fédérale de Lausanne (Lausanne, Switzerland) and the Max-Born-Institute for Nonlinear Optics and Ultrafast Spectroscopy (Berlin, Germany) have demonstrated laser operation of an ytterbium (Yb)-doped waveguide composed of an oxide of potassium (K), yttrium, and tungsten (W) of the specific formula $KY(WO_4)_2$-more commonly referred to as Yb:KYW.[1] Continuous-wave (CW) emission was achieved for both surface and buried planar waveguides. "The slope efficiency of the Yb:KYW waveguide laser is as high as 80.4%, which is, to the best of our knowledge, the highest value ever reported for a dielectric waveguide laser," notes researcher Yaroslav Romanyuk.

To achieve high-power lasing, the researchers fabricated high-quality Yb-doped waveguides using the KYW double tungstate crystal composite. Because large-area defect-free thin layers on a suitable substrate are essential to achieving low-loss propagation of light within the waveguide, a liquid-phase epitaxy (LPE) growth technique was employed in which a single-crystal layer is grown from a molten solution on an oriented single-crystal substrate.
Normally, LPE of rare-earth-ion-doped KYW layers using a low-temperature chloride solvent causes insertion defects that limit the maximum layer thickness to 10 µm and cause poor interface quality between layers. To improve the crystal quality, the researchers used a tungstate solvent ($K_2W_2O_7$) and a vertical dipping technique with partial immersion of the substrate to better control the uniformity of the grown layer on the 1-mm-thick undoped KYW substrate. Single-crystalline layers of thickness 10 to 100 µm and Yb^{3+} doping concentrations between 1.2 and 2.4 at.% were grown at a rate of 18 µm per hour. Spectroscopy confirmed the calculation that the refractive-index change of a 1.8-at.% Yb-doped layer with respect to the undoped substrate was 6×10^{-4}.



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An optical micrograph of the polished end face of a 22-µm-thick buried ytterbium (Yb)-doped waveguide (top) shows no observable defects between the doped and undoped layers. The vertical intensity profile of the output from the waveguide is nearly Gaussian (bottom) when pumped with a 980-nm Ti:sapphire laser in preparation for the lasing experiment.

To obtain active, buried waveguide structures, several doped layers were overgrown with 20-μm-thick undoped layers to create a symmetric refractive-index profile. The polished end face shows that interfaces are sharp and straight without any detectable defects (see figure). Testing the layers as active and passive planar waveguides using a 980-nm pump laser and imaging the output onto a CCD camera showed that at least three TE modes could be supported by a 22-μm-thick planar buried waveguide in the vertical direction.

Two waveguides

For laser experiments, two 17-μm-thick and 6-mm-long waveguides were chosen, with polished surfaces and end faces. One was a 2.4-at.% buried waveguide and the other was a 1.2-at.% surface waveguide. In an astigmatically compensated z-shaped cavity, the waveguide was positioned at the Brewster angle between two folding mirrors with a 10-cm radius of curvature that focused the resonator waist at both end faces of the waveguide to reduce diffraction losses. Pumping the waveguides with a 980.5-nm Ti:sapphire laser produced a stable CW oscillation near 1025 nm for both waveguides, with a 95% linearly polarized output.

Although the buried waveguide should have exhibited lower propagation losses, its performance was slightly inferior to the surface waveguide-probably because of the higher doping concentration that can lead to higher reabsorption losses. For the surface waveguide, 80 mW of absorbed pump power produced a maximum output of 290 mW.

With waveguide losses calculated to be 0.08 dB/cm for the multimode waveguide structure, the laser output is close to the diffraction limit as determined by the observed far-field intensity distribution. The waveguide was mounted on a copper plate without cooling during the experiments.

Gail Overton

REFERENCE

1. Y. E. Romanyuk et al., *Optics Lett. 31*(1), 53 (Jan.1, 2006).

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Author(s): Gail Overton