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Single-frequency and Mode-locked Er/Yb Co-doped Waveguide Lasers

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Rare-earth-doped waveguide lasers have seen a significant increase in commercial and research interest over the last decade both in single-frequency and pulsed laser designs.[1,2,3] This is due primarily to the higher doping concentrations of active ions in rare-earth-doped bulk glasses relative to rare-earth-doped fiber devices. Higher dopant concentrations allow for laser operation at decreased cavity length, which improves mode stability. We present results using Er/Yb co-doped waveguides in cw narrow-linewidth and mode-locked lasers.

The demand for bandwidth in data-transfer-intensive industries such as telecommunications and cable television has increased the need for single-frequency sources operating near 1.55 μm. Single-frequency optical sources that have wavelength selectivity, high output power, long-term stability, longevity, and low fabrication cost are ideally suited to meet this need as well as needs in testing, remote sensing, and instrumentation. Rare-earth-doped fiber lasers with distributed Bragg reflectors (DBRs) have been shown to generate low noise (less than -150 dB/Hz out to 10 MHz) optical output with laser linewidths less than 20 kHz.[4,5] Narrow-linewidth operation near 1.55 μm has also been demonstrated using DBR waveguide lasers.[1] Solid-state DBR waveguide lasers have the added advantage of producing multiple wavelengths on a single, compact laser chip. We present results from DBR waveguide lasers produced in Er/Yb co-doped phosphate glass and in active/passive bonded (hybrid) glass. The waveguides are first fabricated in commercially available rare-earth-doped phosphate glass using a KNO_3 thermal ion exchange process.[1] A DBR grating is then etched on the surface of the 2.2 cm long waveguides using a holographic exposure technique combined with argon-ion milling. The pitch of the grating combined with the gain cross section of the doped glass determines the lasing wavelength of the device. The devices are pumped with a pair of laser diodes (λ = 974 & 981 nm), producing a combined pump power coupled into the waveguide of 150 mW, or alternatively a Ti:Sapphire laser at 977 nm with 500 mW of coupled pump power. The diode-pumped DBR lasers produce 15 mW of 1540 nm radiation, and the Ti:Sapphire pumped DBR lasers produce as much as 85 mW output power. The output wavelength is measured with an optical spectrum analyzer, and the lasers are single-frequency within the 0.05 nm resolution limit of the instrument. Self-heterodyne measurements using a 10 km fiber delay line and a frequency shift of 80 MHz are performed to obtain a more accurate determination of the laser linewidth.[6] Figure 1 compares the detected beat-note spectral width with a diode and a Ti:Sapphire pump. The Ti:Sapphire-pumped system produces a laser linewidth ($\Delta\nu$ ~ 500 kHz typical) that is dominated by pump noise, while the diode-pumped system yields significantly narrower spectral performance ($\Delta\nu$ ~ 17 kHz typical). The beat-note spectrum in figure 2 for the diode-pumped DBR waveguide laser fits the well-known Voigt profile, which takes into account the contributions to the measured linewidth from 1/f noise and the natural laser linewidth.[7]

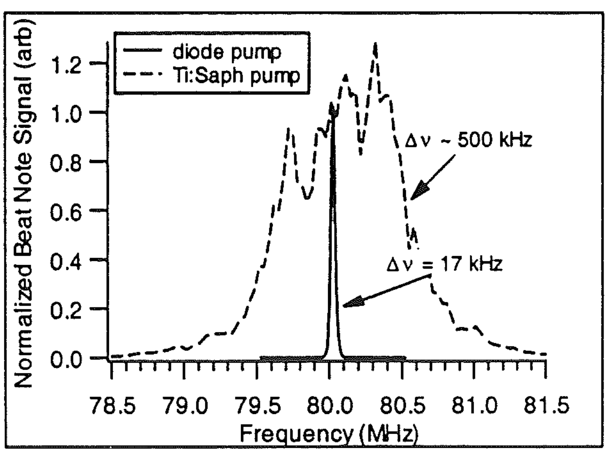

Figure 1. Self-heterodyne spectra for Ti:Sapphire and diode-pumped DBR waveguide laser.

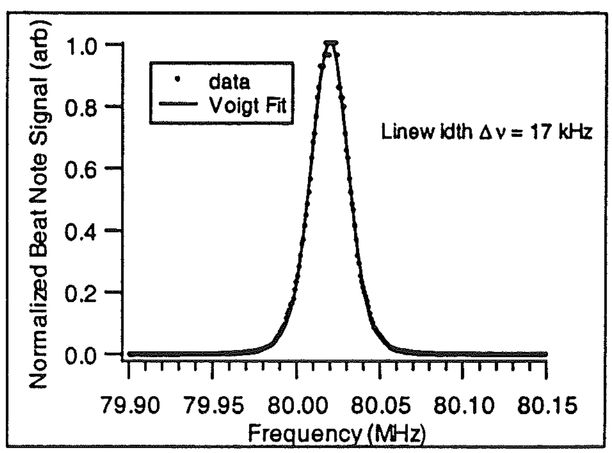

Figure 2. Self-heterodyne spectrum for diode-pumped DBR waveguide laser.

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There is considerable commercial interest in mode-locked lasers for high-data-rate communication systems. High-powered mode-locked lasers with low jitter are required for high-speed A/D conversion in optical sampling of wide-band RF signals. We present results from a passively mode-locked waveguide laser incorporating a semiconductor saturable absorber mirror (SESAM). The waveguides in the laser chip are fabricated using the same thermal-ion-exchange process that is used for the single-frequency lasers. The laser is aligned in an extended cavity configuration with a 20 % output coupler mounted to one end of the chip and the SESAM as the other end mirror of the free space cavity. The free-space facet of the waveguide chip is cut at Brewster's angle to minimize intra-cavity reflections and force a TE polarization state of the laser. The SESAM has three low-temperature grown InGaAs quantum wells in an anti-resonant configuration on top of a 22.5 period DBR consisting of alternating AlAs/GaAs quarter-wave layers. The measured optical properties of the SESAM device are the nonsaturable loss (3% ± 0.5%), saturable loss (ΔR = 9.5% ± 0.5%), and saturation fluence (F_{sat} = 25 μJ/cm^2). The laser system generates stable mode-locking up to 500 MHz with an average output power at 1533.6 nm of 9.3 mW for 150 mW of coupled multiplexed diode pump power (λ = 974 & 981 nm), and 20 mW for 440 mW of coupled Ti:Sapphire pump power at 976 nm. This second result is a 14-fold increase in output power over previous results.[2] Figure 3 shows the time-bandwidth analysis of the laser. The autocorrelation width is 8.2 ps FWHM, corresponding to a Gaussian pulse of 5.8 ps FWHM, and the bandwidth of the laser is 0.62 nm. This yields a time-bandwidth product of 0.46, which is slightly larger than the 0.44 transform limit of a Gaussian pulse. This may indicate that the output pulses are slightly chirped. The timing jitter is measured to be 13 ps. We plan to further decrease the timing jitter with active cavity-length stabilization, environmental isolation, and a combination of active/passive mode-locking. We also plan to increase the repetition rate of the laser above 1 GHz.

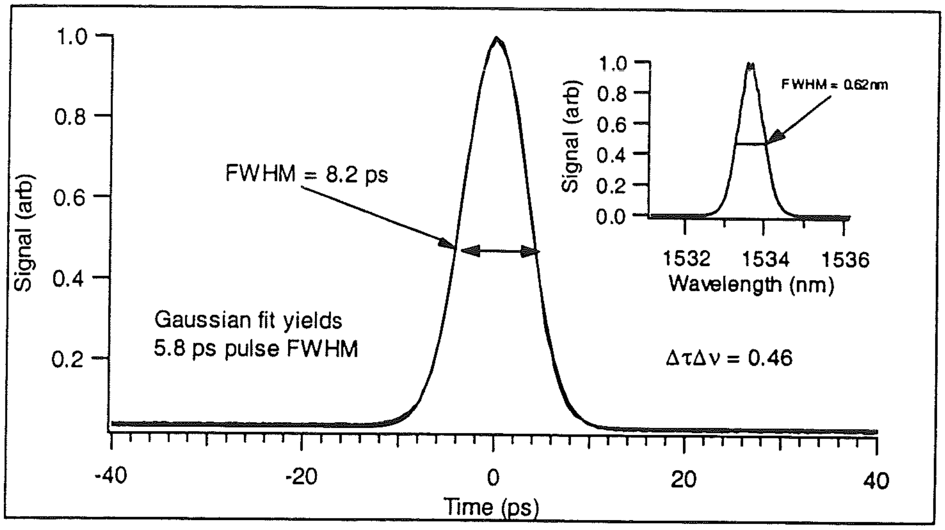

Figure 3. Time-bandwidth analysis of passively mode-locked waveguide laser.

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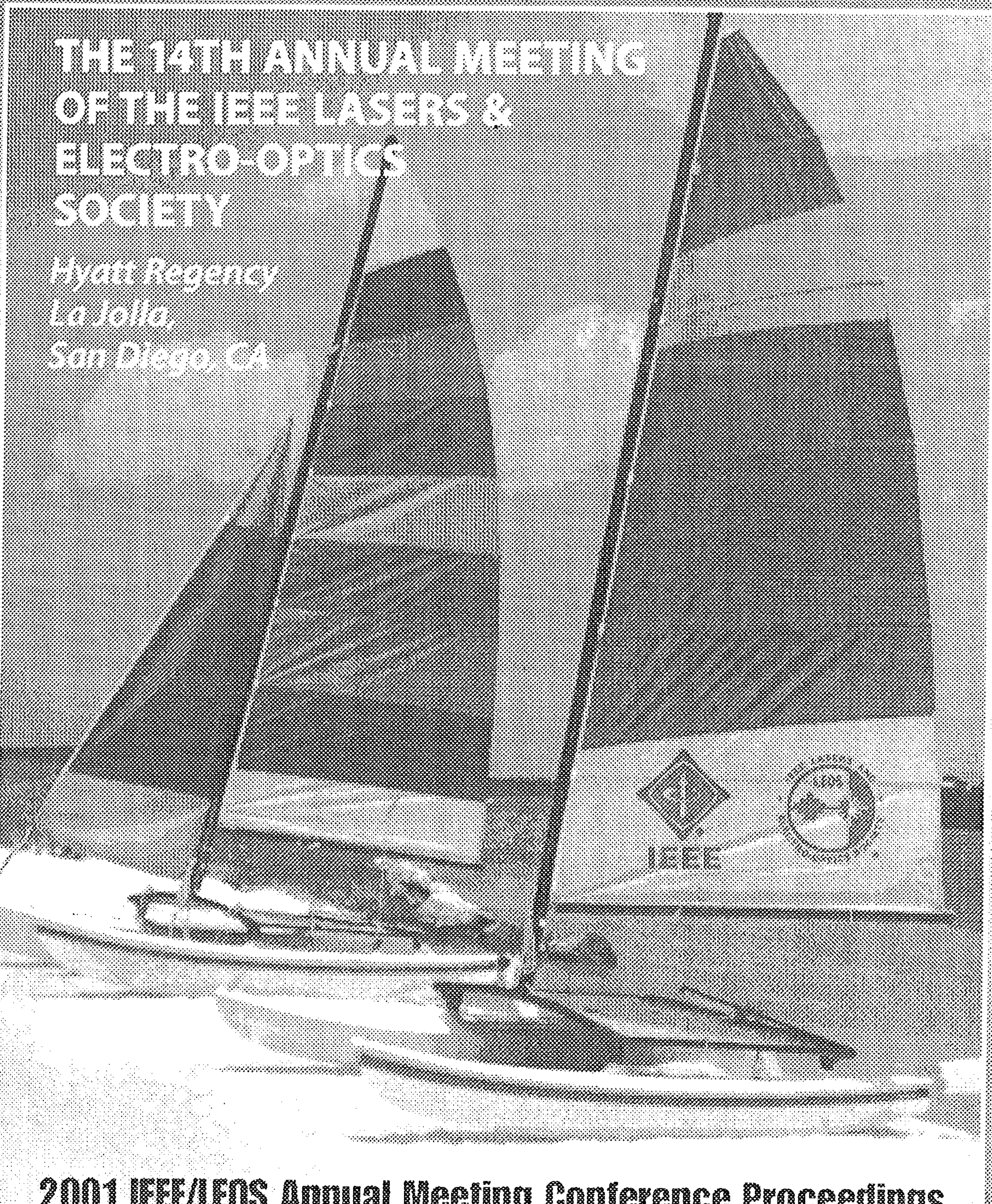

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