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Narrow-linewidth fiber laser operating at 1.55 μm

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We report the fabrication and operation of an Er^{3+}-doped silica single-mode fiber laser operating at 1.55 μm and using a distributed fiber grating to provide feedback. The output bandwidth was measured as 0.04 nm, significantly narrower than the conventional cavity design. The laser had a threshold of 13 mW and a slope efficiency of 5%.

Active devices operating at 1.55 μm, the lowest-loss window for silica, are of great interest not only for optical communications but also for a wide range of related measurements, such as backscatter and sensor applications. To supplement the diode-laser–optical-fiber hybrid technologies currently employed, devices that can be directly spliced into optical-fiber systems are highly desirable. In addition, the introduction of a number of all-fiber devices, such as couplers and filters, increases the possibilities of all-fiber active circuits.

Toward this goal, the development of low-loss rare-earth-doped fibers[1] has led to the construction of a number of single-mode fiber-laser devices.[2] This new class of lasers has numerous advantages; the solid-state nature of the lasers renders them extremely reliable, and they are potentially cheap. In addition, the small active volume allows for low threshold and efficient operation.[3] This has led to widely tunable laser sources,[4] laser action of transitions never previously reported in glass,[5] and the first reported room-temperature cw operation of a three-level glass laser.[6]

The introduction of an integral fiber grating in a fiber-laser cavity was reported previously.[7] In relation to the conventional cavity design, incorporating a fiber grating significantly reduces the linewidth of the laser output from a few nanometers to less than 0.05 nm. This has possibilities for sensor applications and also represents a step toward an all-fiber device.

The fabrication and characteristics of high-reflectivity monomode fiber gratings are described elsewhere.[8] The particular grating used in this experiment was constructed using fiber of 0.12 N.A. and 9-μm core diameter. A thin layer of index-matching fluid was placed on the grating to increase the interaction with the evanescent field in the fiber. By changing the refractive index of the oil it was possible to vary both the spectral response and the reflectivity of the grating, thus allowing for optimum output coupling. The grating used in this experiment was characterized by a peak reflectivity at 1.551 μm of approximately 40% and a FWHM of 1 nm (Fig. 1).

The fiber-laser experimental arrangement is shown in Fig. 2. The pump source was an Ar^{+}-ion-pumped cw DCM dye laser operating at 650 nm. As the particular Er^{3+}-laser transition excited was three-level, it was necessary to use a length of fiber that, while absorbing most of the pump energy, was sufficiently short not to possess an unsaturated absorbing region at 1.55 μm. It was found that a length of 2 m was satisfactory. The doped fiber had a N.A. of 0.22 and a core diameter of 7 μm. The dielectric input mirror was chosen to transmit most (T = 91%) of the pump light while reflecting (R = 99%) the majority of the laser light and maintaining the cavity finesse. The doped fiber was cleaved and butted at one end to the input mirror and at the other to the grating fiber. Some étalon effects at the butt between the doped fiber and the grating fiber ends were observed, and these could be eliminated by placing a drop of index-matching oil on the butt.

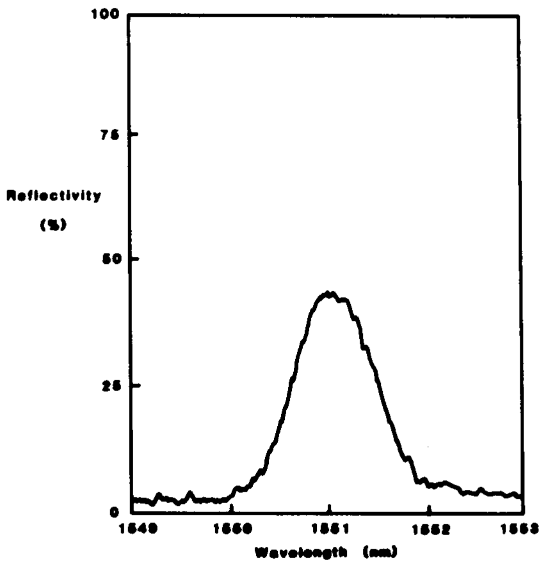

Fig. 1. Reflection characteristic of fiber grating used in the experiment.

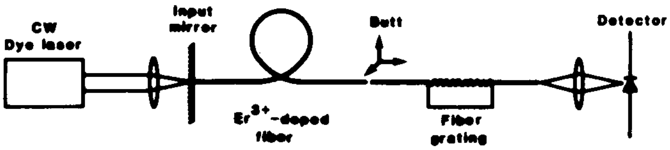

Fig. 2. Experimental configuration of fiber laser operating at 1.55 μm using fiber grating.

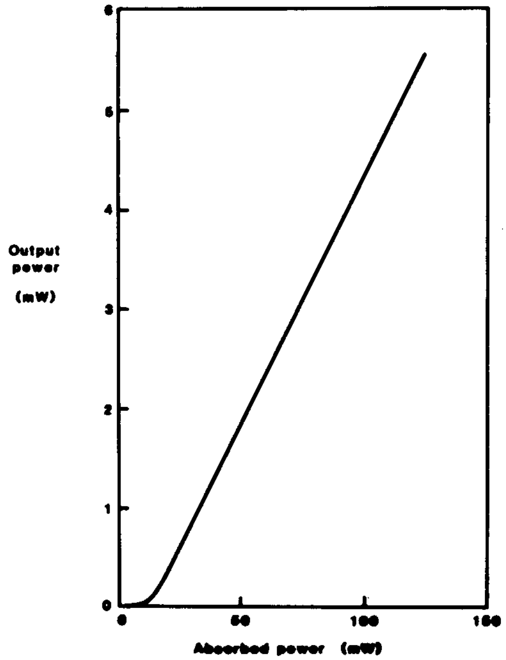

Fig. 3. Er^{3+}-doped single-mode fiber-laser characteristic using fiber grating and 650-nm dye-laser pump.

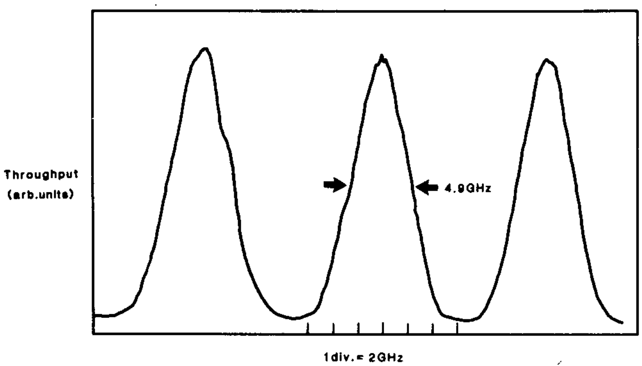

Fig. 4. Scanning Fabry–Perot trace of fiber laser operating at 1.55 μm, showing three orders of transmission.

The lasing characteristic of the fiber laser is shown in Fig. 3. A slope efficiency of 5% and a lasing threshold of 13 mW absorbed were obtained. The slope efficiency was less than that reported previously for a number of reasons. First, the peak grating reflectivity was not centered on the peak of the Er^{3+} fluorescence curve, and so the system was not operating under maximum gain conditions. Second, there was a large round-trip cavity loss, mainly due to the 3.1-dB butt loss. It is expected that reduction of this loss will lead to a significantly more efficient device. It has already been demonstrated[4] that line narrowing of the laser output does not reduce its efficiency.

The spectral characteristics of the laser output were measured using a scanning Fabry–Perot interferometer. The output trace is shown in Fig. 4. The free spectral range (FSR) of the interferometer was 13.8 GHz, and the finesse was estimated to be greater than 100. The laser output had an approximately Gaussian profile in the frequency domain with a FWHM of 4.9 GHz (0.04 nm), corresponding to fewer than 100 longitudinal cavity modes. The laser output linewidth was significantly narrower than that of the grating owing to modal gain competition. Further decrease of the FSR to increase the resolution of the interferometer revealed no new structure and no decrease in FWHM. This indicates that there were no étalons formed by intracavity components, as would be expected if a bulk diffraction grating were used to narrow the linewidth. The laser wavelength was measured as 1551 nm, coinciding with the peak grating reflectivity. This compares with a free-running wavelength of 1536 nm, which is observed with the untuned Er^{3+}-doped fiber laser.

A narrow-linewidth cw fiber laser operating at 1.55 μm has been successfully demonstrated. The laser is based on a cw dye-laser-pumped Er^{3+}-doped fiber and employs a distributed fiber grating to provide feedback. The laser is characterized by a threshold of 13 mW, a slope efficiency of 5%, and an output bandwidth of 0.04 nm.

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References

1. S. B. Poole, D. N. Payne, and M. E. Fermann, **22,** 737 (1985).
2. R. J. Mears, L. Reekie, S. B. Poole, and D. N. Payne, Electron. Lett. **22,** 738 (1985).
3. I. M. Jauncey, J. T. Lin, L. Reekie, and R. J. Mears, Electron. Lett. **22,** 198 (1986).
4. L. Reekie, R. J. Mears, D. N. Payne, and S. B. Poole, IEEE J. Lightwave Technol. **LT-4,** 956 (1986).
5. L. Reekie, R. J. Mears, S. B. Poole, and D. N. Payne, presented at the Institute of Physics/Institute of Electrical Engineers Symposium on Advances in Solid State Lasers, Imperial College, London, May 1986.
6. R. J. Mears, L. Reekie, S. B. Poole, and D. N. Payne, Electron. Lett. **22,** 159 (1986).
7. I. M. Jauncey, L. Reekie, R. J. Mears, D. N. Payne, C. J. Rowe, D. C. Reid, I. Bennion, and C. Edge, Electron. Lett. **22,** 987 (1986).
8. I. Bennion, D. C. J. Reid, C. J. Rowe, and W. J. Stewart, Electron. Lett. **22,** 341 (1986).