Friday **AFTERNOON**
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ROOM P (236)

1:30 PM **Novel Optical Fibers and Fiber Compounds**

Donald B. Keck, Corning Glass Works, Presider

FN1. Rare-earth doped single-mode fiber lasers, amplifiers, and devices

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It is the current widespread use of single-mode optical fiber for telecommunications and the ready availability of high-power semiconductor pump lasers which have recently stimulated interest in single-mode fiber lasers and amplifiers.[1] Until recently, lasing in glass fibers has been carried out in multimode devices.[2,3] Using a new manufacturing process[4] we have shown that single-mode fibers with rare-earth dopant concentrations up to 900 ppm can be made without compromising the low losses (>1 dB/km) which are characteristic of telecommunications fibers. It is thus now possible to construct a wide range of active fiber devices and sensors which exploit the numerous fiber components available, such as four-port couplers, ring-resonators, polarisers and filters.

Single-mode fiber lasers possess a number of advantages over their bulk counterparts. As a consequence of the high pump intensity within the small (>8 µm) core, very low threshold (100 µW) and large gains can be achieved. Moreover, the small fiber diameter minimizes the thermal effects which plague bulk-glass lasers, and high levels of pump power can be absorbed. Silica, the laser medium, has good power-handling properties and, in addition, broadens the rare-earth transitions, thus enabling tunable lasers[5] and broadband amplifiers to be constructed.

As a result of the above attributes, laser action in fibers can be observed using a number of less commonplace rare-earth dopants and transitions, even when the transitions involved are weak. Moreover, continuous laser operation is possible in three-level laser systems which have previously only operated in a pulsed mode.

We have fabricated fibers containing most of the rare-earths and some of the transition metals. Remarkably, all exhibit windows in which losses are low despite the presence of high-loss absorption bands. This permits the construction of long amplifiers and lasers; 300 m has been demonstrated, as well as nonlinear devices and distributed sensors, although long lengths are not necessary to obtain lasing action.

A typical fiber-laser configuration is shown in Fig. 1. For Nd^{3+} doped fibers, a lasing threshold as low as 100 µW can be obtained using a semiconductor laser end-pump.[1] In an optimized cavity an output exceeding 1 mW at a wavelength of 1088 nm has been observed[6] with a slope efficiency of 30%. Tuning of the output wavelength can be accomplished by substituting a grating for one of the mirrors and, with an Ar-ion laser pump (51 mW of pump absorbed), a 80-nm tuning range is possible. We believe this is the most extensive tuning range yet obtained in a Nd:glass laser and compares favorably with that of a dye laser. In addition, 17 dB of gain has been measured in a short length of Nd^{3+}-doped fiber, indicating the potential for high-gain optical fiber amplifiers.

Erbium-doped fiber lasers operate between 1530 and 1555 nm, which coincides with the important minimum-loss window for optical communications. The fluorescence spectrum is shown in Fig. 2 and corresponds to the $^4I_{13/2}$–$^4I_{15/2}$ (ground-state) transition. Despite being a 3-level laser system, the Er^{3+}-doped fiber laser operates continuously[8] and has a threshold of only 4 mW. To our knowledge this represents the lowest threshold and only room temperature cw three-level glass laser yet reported. The laser tuning curve when pumped at 514.5 nm (90 mW absorbed) is also shown in Fig. 2.

Q-switching of fiber lasers[5,7] using an acoustooptic modulator or rotating chopper is also possible and peak powers of several watts have been observed in pulses ranging from 50 ns and 1 µs.

Figure 3 compares the fluorescence spectrum of a Pr^{3+}-doped fiber with the laser turning curve. Pumping was by a cw Rh6G dye laser operating at 590 nm and the output could be tuned from 1060 to 1107 nm. Threshold for this dopant was 10 mW and an output of several mW could be obtained.

Fiber lasers represent a new class of active fiber devices which are fully compatible with existing fiber components. Their low threshold, tunability and high peak-power pulsed output provides a unique new all-fiber laser technology which will find application in telecommunication and fiber sensors. Immediate potential uses are as a high-power source for fiber OTDR measurements and as a broadband emitter for the optical-fiber gyroscope. Progress toward these and other potential applications will be reviewed.

(Invited paper, 25 min)

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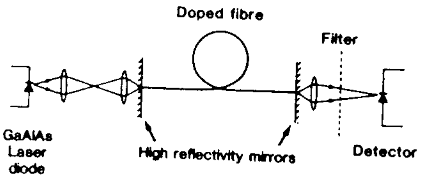
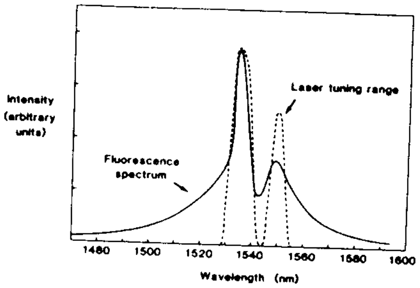
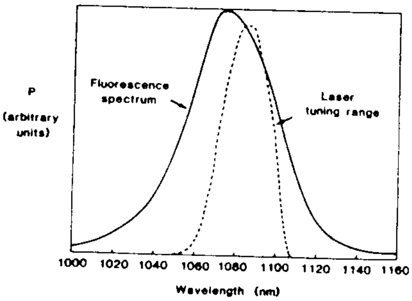


FN1 Fig. 1. Experimental configuration of a semiconductor laser pumped single-mode fiber laser.



FN1 Fig. 2. Laser tuning range and fluorescence spectrum of Er^{3+}-doped single-mode fiber laser.



FN1 Fig. 3. Laser tuning range and fluorescence spectrum of Pr^{3+}-doped single-mode fiber laser.