Rare-Earth-Doped Fiber Lasers and Amplifiers

OPTICAL ENGINEERING

Rare-Earth-Doped Fiber Lasers and Amplifiers

Second Edition, Revised and Expanded

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MARCEL

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Since this work, extremely efficient 1.48–μm-pumped Er-doped fiber lasers have in fact been reported by Wagener et al. at Stanford University [107]. This study established that a key factor that needs to be optimized to maximize the conversion efficiency is the erbium concentration. Measurements indicated that fibers with increasingly high Er concentrations have increasingly high thresholds and low slope efficiencies. These two effects were attributed to the presence of an increasing percentage of Er^{3+} clusters, and to the fact that clusters dramatically reduce the excited lifetime [133], and thereby the quantum efficiency of the transition. The most efficient fiber laser reported in this study used a low-concentration fiber (110 mol ppm Er_2O_3) and a correspondingly long fiber (42.6 m) [107]. The cleaved fiber ends (~3.5% reflections) formed the laser Fabry–Perot resonator. In spite of the high cavity loss (~29 dB), the threshold was low (~4.8 mW), and the laser was successfully pumped with a low-power laser diode. It emitted simultaneously in the forward and backward direction, with a forward slope efficiency of 58.6% [107]. This is the highest slope efficiency and the highest conversion efficiency reported in an Er-doped fiber laser (see Table 3). The backward slope efficiency was 31.8%. If a dichroic high reflector was placed at the pump input end, a total slope efficiency of approximately the sum of these two figures, or ~90.4%, would be expected, as well as a substantial reduction in threshold.

This study showed that Er-doped fiber lasers, when pumped near 1.48 μm, can be at least as efficient as 980-nm pumped lasers. The reasons for this high performance were the low Er concentration and the similarity between the pump and laser photon energies [107]. The slope efficiency of 90.4% is, in fact, very close to the quantum limit of 95% predicted for the ratio of pump to signal photon energies. It confirms that the quantum efficiency of this transition can be within a few percent of unity. In this light, concentration quenching may well explain the suboptimal efficiencies and thresholds reported in some Er-doped fiber lasers (see Table 3). It points to the importance of selecting a sufficiently low rare earth concentration to maximize the performance of fiber lasers or amplifiers. This requirement was confirmed in a more recent report of a ring fiber laser that utilized a very low-concentration fiber (see Table 3) [21]. After optimizing the fiber length and output coupler transmission, the laser had a low threshold (6.5 mW) and a fairly high slope efficiency of 38.8%. Tuning from 1525 to 1570 nm was achieved with an intracavity tunable filter.

3.6.8 Summary

In summary, Er-doped fiber lasers operating close to 1.55 μm are extremely efficient. When pumped at 1.48 μm, their slope efficiency can be within a few percent of the theoretical limit $\lambda_p/\lambda_s \approx 95\%$. Pumping at 980 nm produces a lower, although still substantial, slope efficiency (theoretical limit of ~63%). Pumping at about 800 nm is unfortunately less efficient (~15%) because of pump ESA, even with Yb co-doping. Er-doped fiber lasers are now almost exclusively pumped close to 980 or 1480 nm. They have also been operated at multiple wavelengths simultaneously. This feature, of great importance for dense WDM systems, is reviewed in Chapter 5.

3.7 YTTERBIUM

3.7.1 Basic Spectroscopy

Ytterbium is one of the most versatile laser ions in a silica-based host. It offers several very attractive features, in particular an unusually broad absorption band that stretches

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