1.5μm Er^{3+}:Yb^{3+}-Doped Fiber DFB Laser

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Abstract

We report the first DFB fiber laser. When pumped with a 980nm diode laser, the 2cm-long laser has an output power of 2mW at 1.534μm and a RIN of < -156dB/Hz.

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Summary

Short, single-frequency Er^{3+}-doped fiber lasers using photorefractive grating feedback [1] are emerging as an interesting alternative to DFB diode lasers for use in high-capacity WDM communication systems, as well as in LIDAR, fiber-optic sensor and spectroscopy applications. Fiber lasers have low noise and kHz linewidths, are temperature insensitivity and fiber compatible, and are scalable to high output powers. By co-doping the Er^{3+}-doped fiber with Yb^{3+}, and thus increasing the pump absorption at 980nm, we have recently shown [2], [3] that the over-all slope efficiency of such short (cms) single-frequency DBR fiber lasers can be increased to 22%, i.e. by two orders of magnitude, to give a diode-pumped output power of 19mW.

Unfortunately, the alumino-phosphosilicate Er^{3+}:Yb^{3+}-doped fiber used in the above DBR experiment [3] is not photosensitive, and therefore the 2cm-long grating had to be spliced to the doped fiber, making the laser longer than necessary and introducing intra-cavity splice loss. However, recently we have succeeded in writing photorefractive gratings with >99% reflectivity directly in the Er^{3+}:Yb^{3+}-doped fiber by loading the fiber with hydrogen. As a result we have now constructed the first DFB fiber laser. DFB lasers have all the advantages of DBR fiber lasers, with the additional advantage of better frequency stability.

The DFB fiber is shown in Fig. 1 and consisted of a 2cm-long uniform photorefractive grating with a refractive index modulation of about $2.1 \cdot 10^{-4}$ written in the same Er^{3+}:Yb^{3+}-doped fiber as reported in Ref. [3]. Calculations [4] show that this configuration requires a single-pass net gain of about 1.1dB to reach threshold, while the Er^{3+}:Yb^{3+}-doped fiber has a maximum gain (ie fully-inverted) of only 1dB in the grating length. To reach threshold therefore requires a longer grating. We instead chose to butt the fiber grating to a 100% mirror, thus effectively doubling the grating length and reducing the threshold equivalent to 0.55dB. This configuration has the additional advantage that all laser power is emitted at one end of the laser. The threshold diode pump power was found to be 7mW, while the over-all slope efficiency was about 5% (see Fig. 2). This relatively low efficiency is believed to be due to the small output coupling from this strong grating relative to the loss.

The output spectrum from the laser is shown in Fig. 3a) and has two peaks centered around the Bragg wavelength, as expected for a uniform (ie non-phase-shifted) DFB laser [4]. The mode separation is about 0.25nm (32GHz), in close agreement with the theoretical prediction of 0.23nm [4]. Note that it was possible to make the laser oscillate on only one of the two modes (Fig. 3b) by slightly displacing the mirror, thus changing the phase relationship between the mirror and the grating. The relative intensity noise of the laser at maximum pump power was as low as -156dB/Hz above 100MHz.

It is clear that the optimization of the DFB fiber laser will lead to considerably improved performance compared to these first results. For example, the threshold gain required will be substantially reduced by introducing an optical phaseshift of $\pi/2$ in the middle of the grating, thus enabling a single mode to exist at the Bragg wavelength where the feedback is strongest [4]. Experiments are currently underway to verify this.

References

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Fig. 1 Er^{3+}:Yb^{3+}-doped fiber DFB laser configuration

Fig. 2 Laser output power relative to total diode pump power.

Fig. 3 Optical spectrum of DFB fiber laser. a) Characteristic double-mode spectrum with a wavelength separation between the two DFB modes of 0.25nm. b) Single-mode operation obtained by slighly displacing the mirror. The linewidth of the individual peaks is limited by the 0.1nm resolution of the spectrum analyzer.

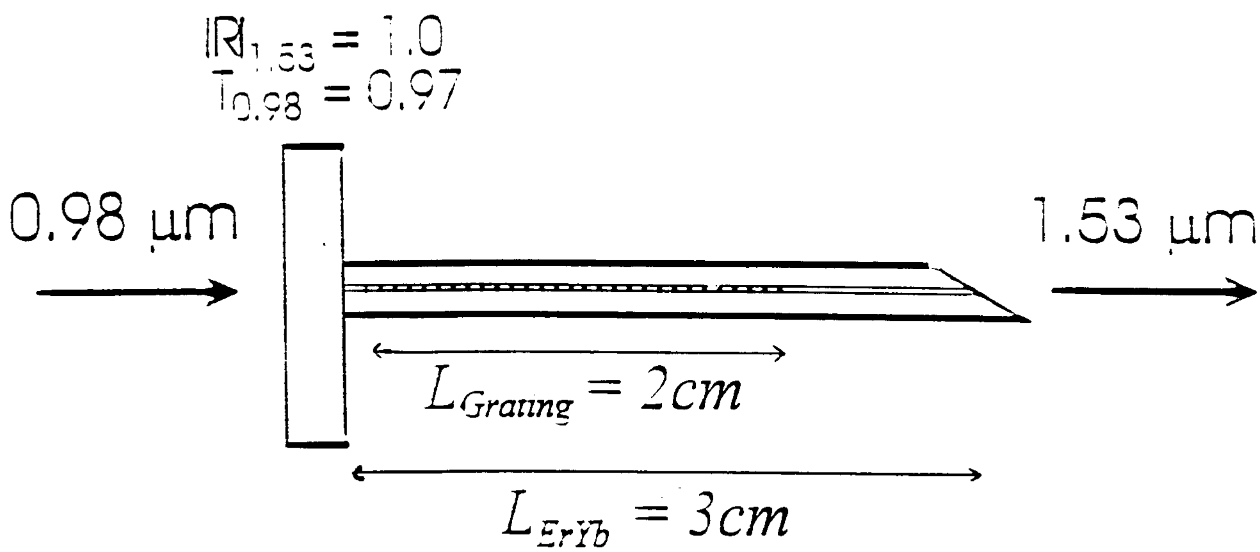

Fig. 1

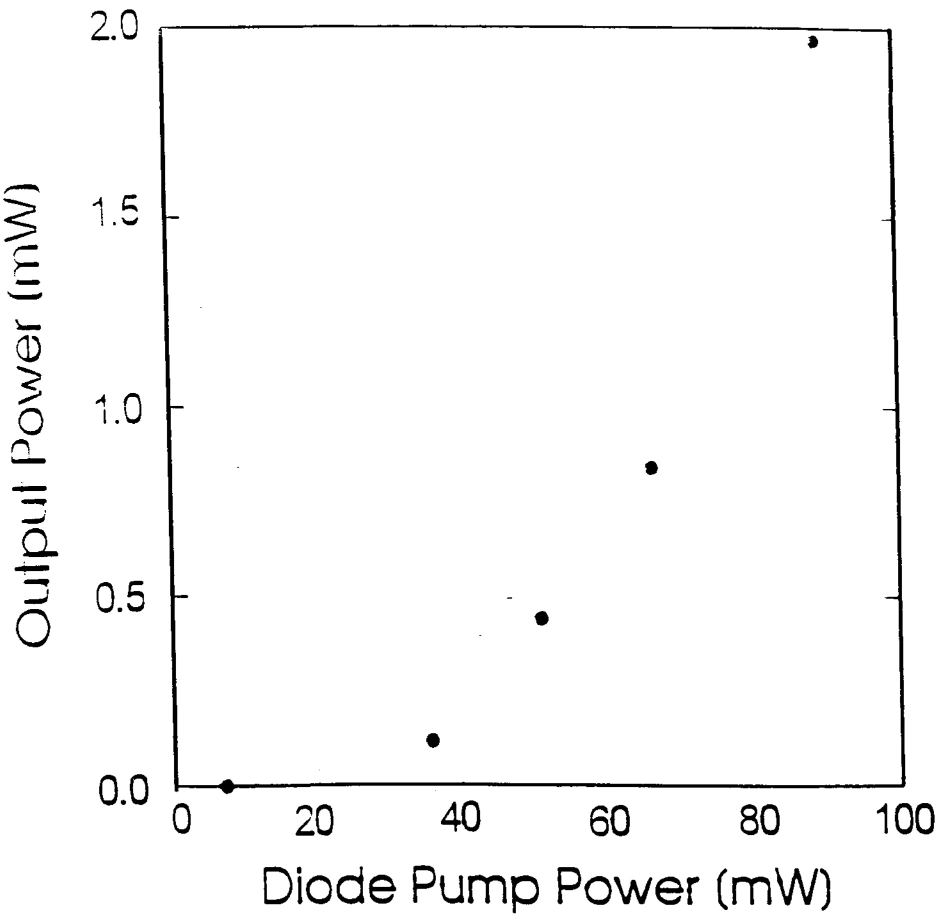
2.0
1.5
1.0
0.5
0.0
Output Power (mW)
0
20
40
60
80
100
Diode Pump Power (mW)

Fig. 2

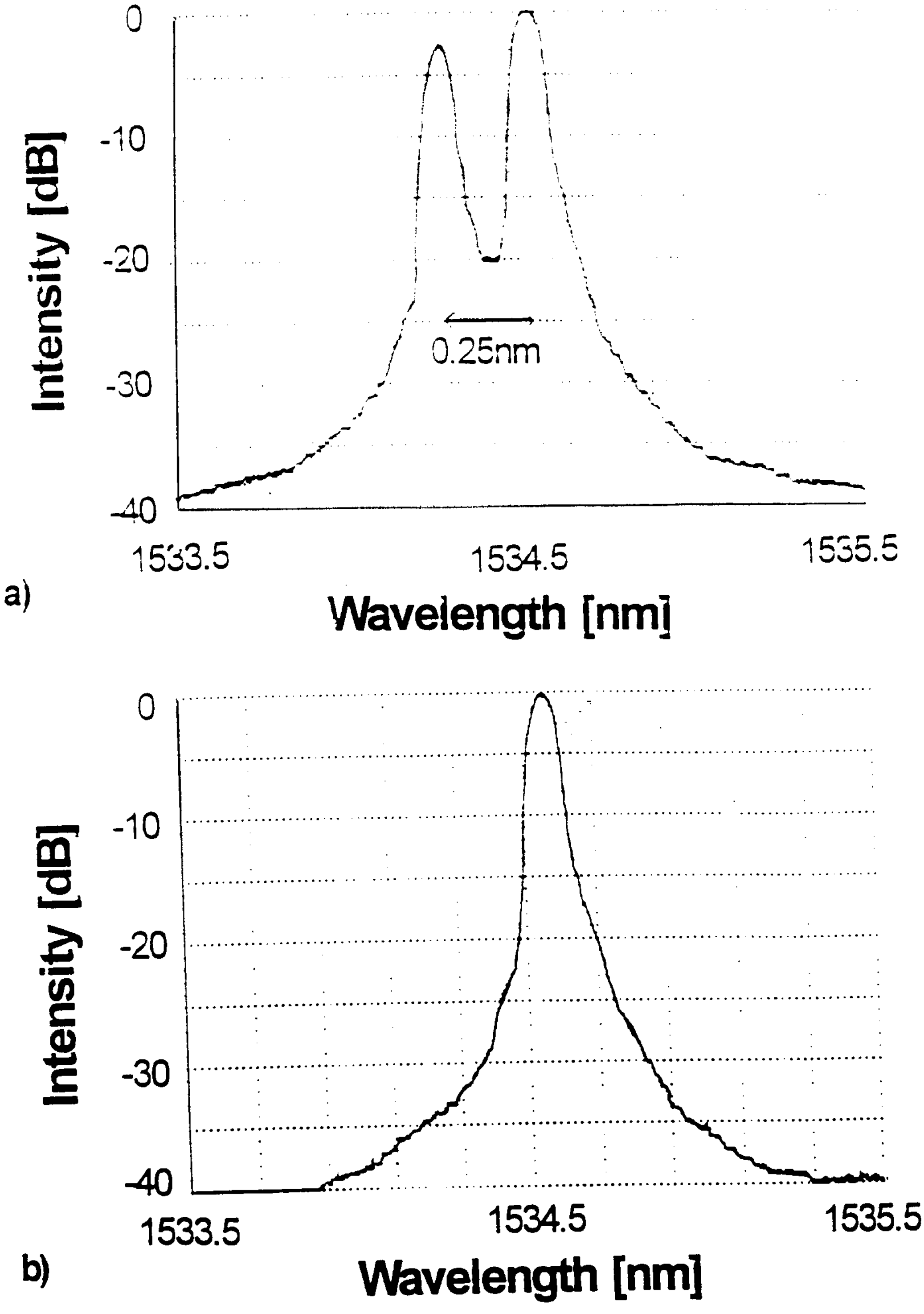
0
-10
-20
-30
-40
Intensity [dB]
0.25nm
1533.5
1534.5
1535.5
a)
Wavelength [nm]
0
-10
-20
-30
-40
Intensity [dB]
1533.5
1534.5
1535.5
b)
Wavelength [nm]

Fig. 3