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Tunable Erbium:Ytterbium Fiber Fabry-Perot Micro Laser

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Abstract

A novel erbium:ytterbium fiber Fabry-Perot laser with a 100-um cavity length is demonstrated to operate in single-mode at 1535nm with a continuous wavelength tuning range over 4.52 nm. This is the shortest fiber laser ever reported.

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Erbium fiber lasers emitting in the 1.55-um wavelength region have been under intensive research for applications in telecommunications, spectroscopy and sensors. Single-mode fiber lasers constructed with either Fabry-Perot cavities or ring cavities usually require wavelength filtering components such as external gratings [1], in-fiber gratings [2], and Fabry-Perot filters [3]. Wavelength tuning can subsequently be achieved by filter adjustments. Recently a microchip erbium:ytterbium (Er:Yb) phosphate-glass laser has achieved single-mode operation in a 200-um Fabry-Perot cavity without additional filtering [4]. Here we report a compact tunable single-mode fiber laser using a novel combination of an Er:Yb phosphate-glass fiber (developed under contract to Amoco Technology Company) within a fiber Fabry-Perot (FFP) cavity [5]. Attractive features of Er:Yb phosphate glass include efficient pump absorption at 980 nm of the Yb ions and large stimulated emission cross-section of Er in phosphate glass. FFP technology allows fabrication of very short cavities (~8 um) and continuous wavelength tunability with low loss. We demonstrate the shortest Er:Yb phosphate-glass FFP laser ever reported, having a 100-um cavity length and a continuous wavelength tuning range over 4.52 nm, as limited by the sharp gain peak.

The FFP laser structure is sketched in Fig.1. Note that the master-oscillator-power-amplifier (MOPA) design can be conveniently implemented to utilize the high residual pump power, as demonstrated in this paper. The laser cavity is mounted in a piezoelectric transducer (PZT) stage capable of air-gap tuning. The phosphate fiber has Er:Yb dopings of 1600:38000 ppm respectively, and a cut-off near 1000 nm. Laser cavity lengths (l) investigated range from 1 mm to 55 um. Single-frequency lasing, though not stable, was possible for l=500 um with mirror reflectivities R1=99.9% and R2>99.0%, and stable single-frequency for l<200 um with R1=R2=99.9%. The minimum cavity length for laser action with 99.9% mirrors is calculated to be ~50 um assuming no intra-cavity loss; however, the shortest successful length was found to be 100 um and the next cavity length attempted (55 um) failed to lase.

Fig.2(a) shows the laser output versus launched pump power (P_p) of the 100-um (R1=R2=99.9%) and the 500-um long lasers (R1=99.9%, R2=99.4%). The 100-um long laser has a maximum output power of ~21 uW and a slope efficiency of ~0.07% before saturation at P_p~30 mW, while the 500-um long laser has a maximum output power of ~0.6 mW at P_p~42 mW and a power slope efficiency of ~2.6%. The observed output saturation is believed to be a thermal effect. In a MOPA configuration, i.e., with an Er-doped fiber (length=2.5 m, NA=0.11, cut-off=1400 nm, [Er^{3+}]=0.09wt%) spliced to the output fiber pigtail, and pumped by the residual pump power (maximum 18 mW), the maximum output power of the 500-um long laser is 4 mW.

Continuous wavelength-tuning over 4.52 nm (i.e., 59% of free spectral range (FSR)) without mode-hopping of the 100-um long laser is shown in Fig.2(b) using a tuning voltage from 0 to 14.3 V on the PZT. For comparison, the experimental tuning ranges as a fraction of FSR of the 199, 158, and 100-um cavities are similar, being 77%, 76%, and 59% respectively. This suggests that the tuning range is limited by the sharp Er^{3+} gain peak in phosphate glass.

Fig.3 shows a delayed self-heterodyne measurement of the linewidth of the 500-um long laser (R1=R2=99.9%) at the maximum output power of 250 uW (P_p=42 mW). The center linewidth is ~500 KHz. The relaxation oscillation at ~2 MHz causes sidebands in the optical spectrum which are responsible for the observed sidebands in the electrical beat-spectrum in Fig.3. The relaxation oscillation frequency of the 100-um long laser is ~1.4 MHz at P_p=42 mW, yielding similar sidebands in the optical spectrum.

In conclusion, we have developed the first tunable fiber micro-laser. The performance can be considerably improved by better phosphate fiber and mirror designs and this should improve the output power, linewidth, and tuning range of the FFP laser.

Reference

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Tunable Erbium:Ytterbium Phosphate Fiber Fabry-Perot Laser

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Figure Caption

Fig.1 Er:Yb FFP laser configuration.

Fig.2 (a) Laser output power versus launched pump power of the 100-um and 500-um long Er:Yb phosphate-glass FFP lasers. Also shown is the output power versus pump power of the 500-um laser in a MOPA configuration (with a 2.5-m long Er-doped fiber at the output). (b) Wavelengths displayed at 9 voltages over a 4.52-nm tuning range of the 100-um laser.

Fig.3 Self-heterodyne measurement of the linewidth of the 500-um long laser using a 25-Km delay line.

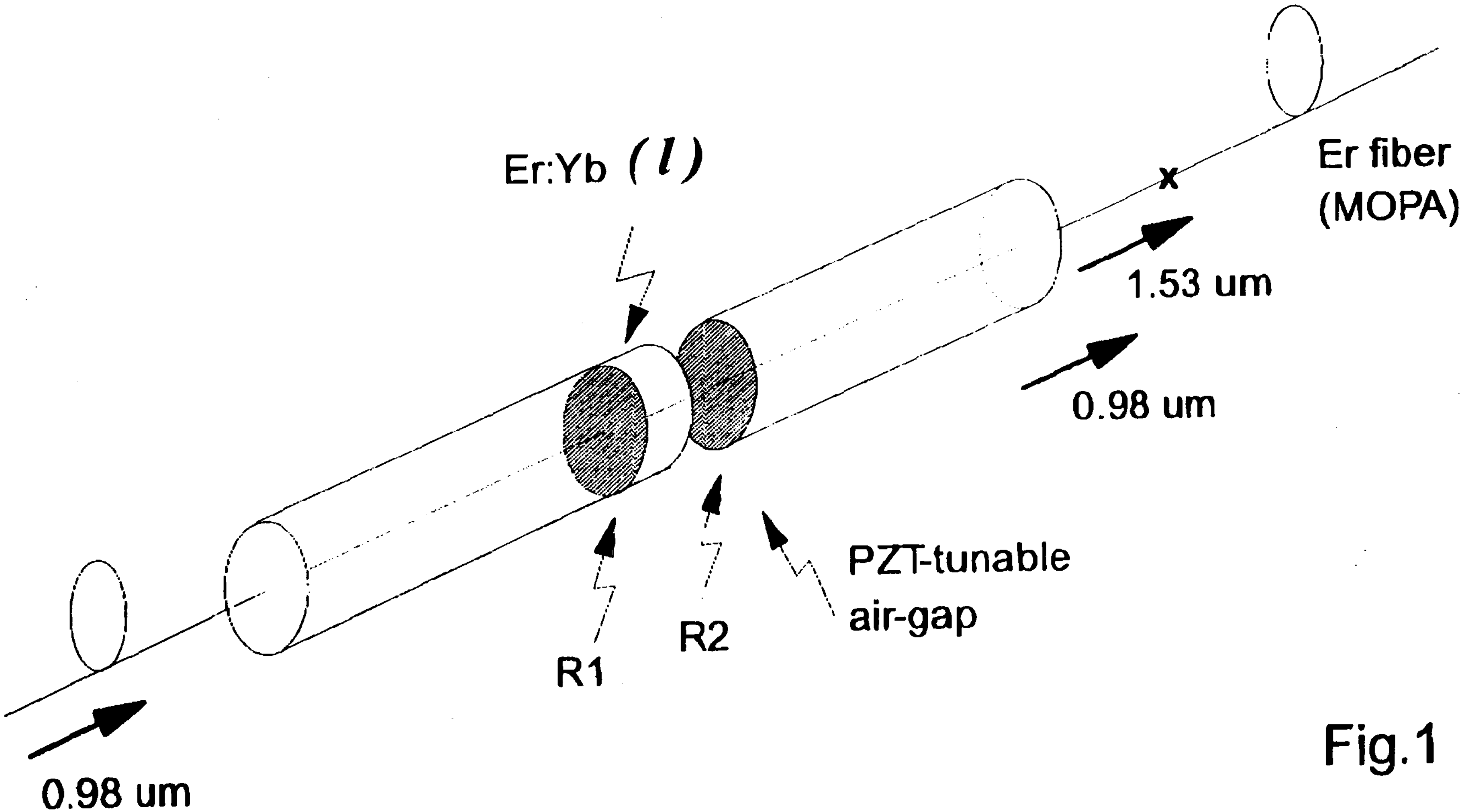

Er:Yb (l)
Er fiber
(MOPA)
1.53 um
0.98 um
R1
R2
PZT-tunable
air-gap
0.98 um

Fig.1

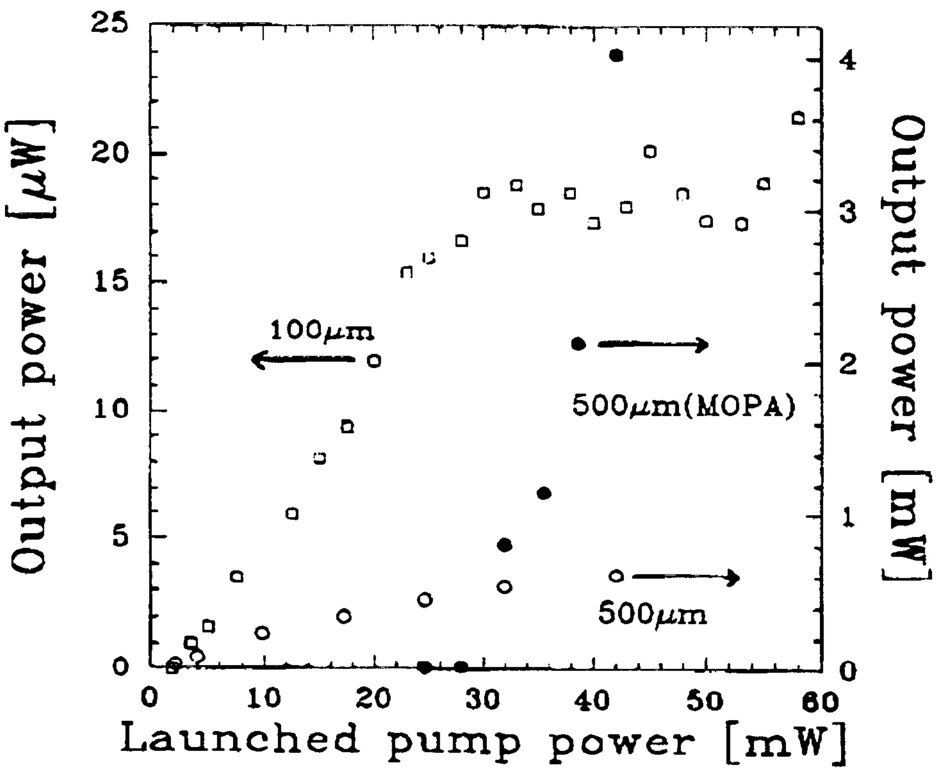

Output power [μW]
Output power [mW]
Launched pump power [mW]
100μm
500μm(MOPA)
500μm
0
5
10
15
20
25
0
1
2
3
4
0
10
20
30
40
50
60

Fig. 2a

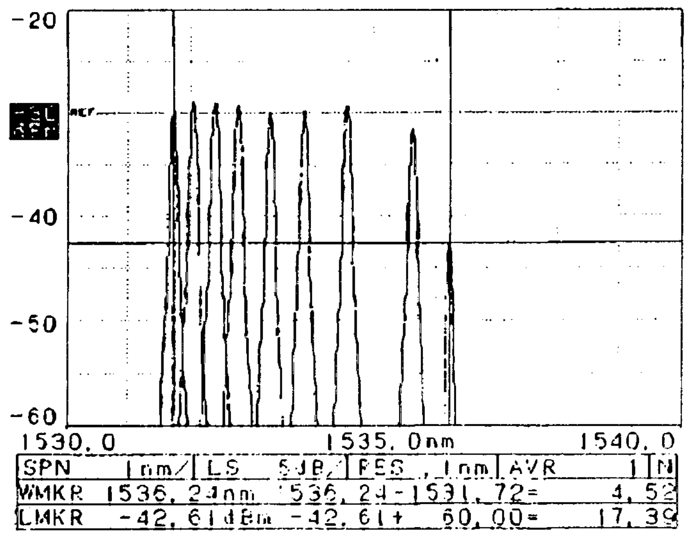
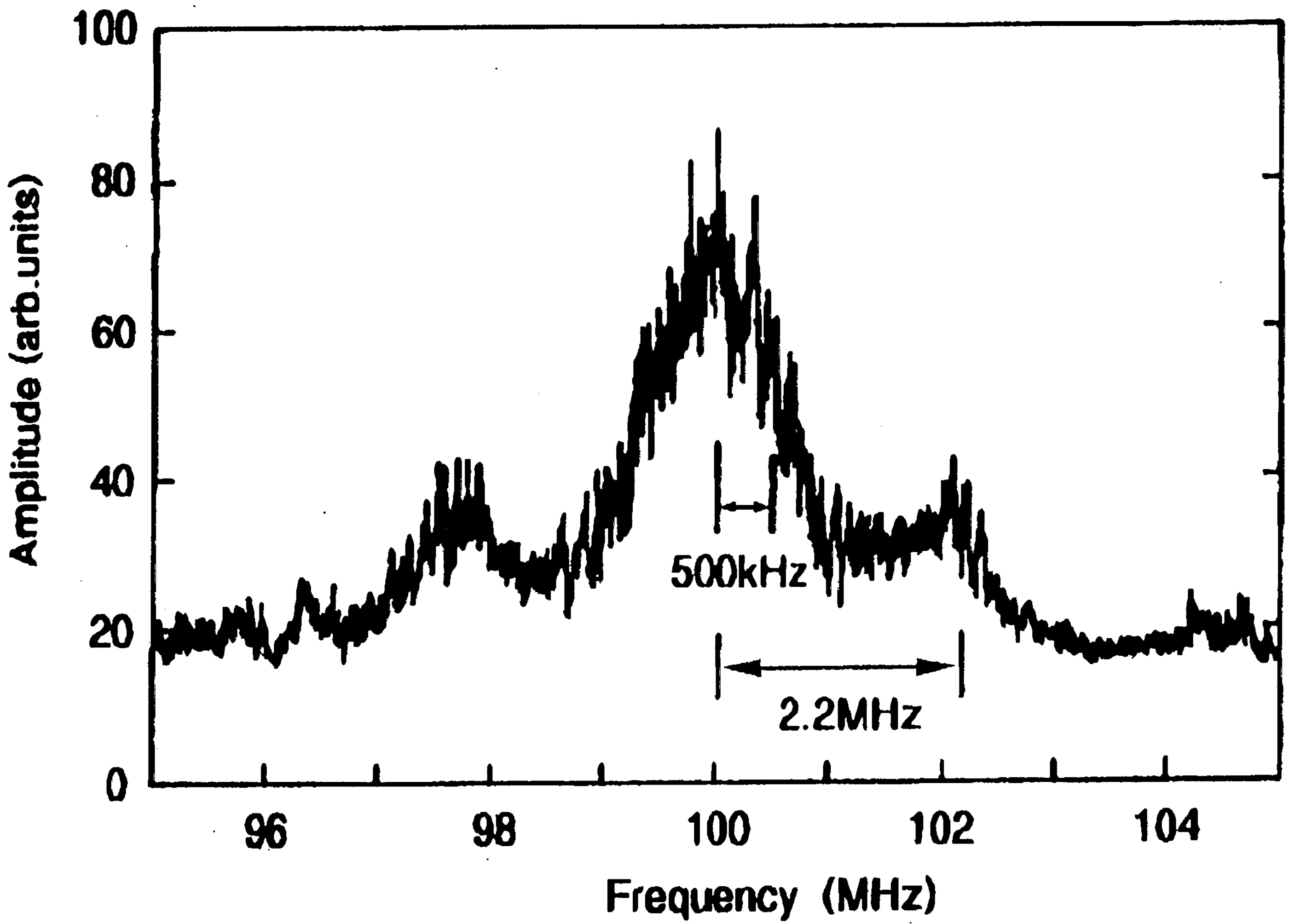

-20
-40
-50
-60
1530.0
1535.0nm
1540.0
SPN 1nm/ LS 5dB/ RES .1nm AVR 1 N
WMKR 1536.24nm 1536.24-1531.72= 4.52
LMKR -42.61dBm -42.61+ 60.00= 17.39

Fig. 2(b)



100
80
60
40
20
0
Amplitude (arb.units)
500kHz
2.2MHz
96
98
100
102
104
Frequency (MHz)

Fig. 3