Electrooptic Narrow Linewidth Wavelength Tuning and Intensity Modulation of an Erbium Fiber Ring Laser

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***Abstract*—We report an electrically tunable fiber laser featuring a 50-channel wavelength switching capability with a 0.2 nm linewidth and −20 dB crosstalk. The laser consists of an Er-doped fiber resonator and an electro-optic TE-TM convertor used as a wavelength tunable filter. It allows wavelength tuning over a spectral range of 10 nm with a tuning rate of 0.05 nm/V and a linewidth of 0.06 nm.**

I. INTRODUCTION

AN INTERESTING method of wavelength tuning fiber lasers consists in using an electrooptic tuner as the wavelength selective element, as was demonstrated for external cavity semiconductor lasers [1]–[3]. Electrooptic birefringent filters matched to fiber ring lasers were reported recently, using bulk two-element tuners formed by an electro-optic modulator [4] or a liquid crystal valve [5], [6]. However the basic principles of most of such tuners rely on two-wave interference, that results in a low spectral selectivity and a broad laser linewidth (~3 nm) when used in fiber laser. In this letter, we report an electrically tunable fiber laser in which the tuner is an integrated $LiNbO_3$ polarization convertor. The advantage of such a structure is its Fabry–Perot-like spectral transmission curve which allows a laser linewidth 50 times narrower than that obtained with birefringent tuners.

II. DESCRIPTION AND DISCUSSION

The set-up (Fig. 1) consists of a fiber amplifier, an $LiNbO_3$ integrated wavelength tuner connected to two crossed fiber polarizers P_1 and P_2, an optical isolator and a 90/10 coupler as the output mirror. The fiber amplifier is a 30-m-long erbium-ytterbium co-doped fiber pumped by a YAG laser at 1060 nm. The gain of the amplifier can be adjusted up to 18 dB and is relatively flat over a bandwidth of $\Delta\lambda = 25$ nm centered at $\lambda_o = 1542$ nm. The overall length of the cavity is 32 m, corresponding to an optical path length in air of ~50 m.

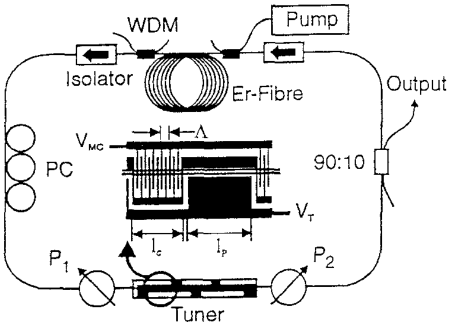

Fig. 1. Experimental set-up.

The tuner is a TE-TM mode convertor which operates as a wavelength tunable selective polarization filter. The structure used is one of the most efficient to obtain TE-TM conversion with electro-optic wavelength tunability [7]. Such a device has been demonstrated to tune external cavity laser diodes [8] and a filter linewidth of ~2 nm was shown to be sufficient to obtain single-mode laser emission. Due to their long cavities, a greater wavelength selectivity is however required in fiber lasers to obtain laser emission with a narrow linewidth. In our device, a high efficiency of light coupling between the tuner and the 6-μm-core of the amplifying fiber is easily obtained, as compared with an extended cavity semiconductor laser in which the light from the tuner is launched in the 0.2-μm-wide semiconductor waveguide.

The TE-TM convertor is formed by a Ti-indiffused waveguide integrated on a 50 mm long x-cut, y-propagation $LiNbO_3$. The electrodes are formed by $M = 60$ TE-TM mode convertor sections, and $M = 60$ phase shifter sections. Each TE-TM mode convertor section is of length $l_c = 12\Lambda = 255.6$ μm and consists of 12 interdigital electrodes with period $\Lambda = 21.3$ μm, all driven by a voltage V_{MC}. The phase shifter sections are formed by electrode pairs of length $l_p = 24\Lambda = 511.2$ μm and driven by a tuning voltage V_T. A complete description of the mode of operation is given in [7]. The spectral transfer curve of the filter is shown to exhibit a transmission peak centered at

$$\lambda_o = |N_{\mathrm{TE}} - N_{\mathrm{TM}}|_{ph} \cdot \Lambda \tag{1}$$

and periodic depleted satellite peaks spaced by a free spectral range expressed as, in wavenumbers:

$$\mathrm{FSR} = 1/|N_{\mathrm{TE}} - N_{\mathrm{TM}}|_{gr} \cdot (l_c + l_p) \tag{2}$$

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where $|N_{\mathrm{TE}} - N_{\mathrm{TM}}|_{ph} = 0.073$ is the phase index difference for the TE and TM modes, and $|N_{\mathrm{TE}} - N_{\mathrm{TM}}|_{gr} = 0.08$ is the group index difference at 1550 nm. Expression (1) is the phase-matching condition for which an input TE-polarized light of wavelength λ_o is totally converted into a TM-polarized light. It gives the finger electrode period $\Lambda = 21.3$ mm required for operation at the center wavelength $\lambda_o = 1542$ nm of the gain curve of erbium. The values of $l_c = 12\ \Lambda = 255.6\ \mu$m and $l_p = 24\ \Lambda = 511.2\ \mu$m were chosen to obtain a FSR of ~40 nm much greater than the bandwidth (25 nm) of the amplifier to avoid mode competition with satellite wavelengths. Neglecting modal dispersion, the full width at half maximum (FWHM) of the filter is

$$\delta\lambda \approx 0.8\lambda_0\Lambda/L \tag{3}$$

where $L = M(l_c + l_p)$ is the total length of the electrode pattern. Hence, a high wavelength selectivity requires the overall electrode pattern to be as long as possible. In the present device, the overall electrode length is of $L = 42$ mm, that is the maximum length achievable at present time at our laboratory yielding a linewidth of $\delta\lambda \approx 0.6$ nm. In fact, in the steady-state regime, laser oscillation requires a number n of trips in the loop, and the laser linewidth is ruled by $T^n(\sigma)$, rather than by $T(\sigma)$. Moreover, due to the competing wavelength-selective mechanisms, the spectral selectivity is expected to be greatly enhanced. The tunable wavelength shift induced by the tuning voltage V_T applied on the phase shifter electrodes is shown to be given by [7]

$$\Delta\lambda \approx -\frac{1}{2}[N_{\mathrm{TE}}^3 r_{33} - N_{\mathrm{TM}}^3 r_{13}]\Gamma\frac{l_p}{l_c + l_p}\frac{\Lambda}{G}V_T \tag{4}$$

where $\Gamma \sim 0.6$ is the normalized overlap coefficient of the E_z electric field with the optical modes, G is the electrode gap ($G = 10\ \mu$m), and r_{13} and r_{33} are electrooptic coefficients ($r_{13} \approx 10$ pm/V, $r_{33} \approx 30$ pm/V).

III. EXPERIMENTS

The tuner was fabricated on a 50-mm-long x-cut LiNbO$_3$ substrate by titanium indiffusion, the titanium stripe width and thickness being 9 μm and 800 Å, respectively. The diffusion was performed in a water rich atmosphere at 1020 °C for 8 h. In order to reduce the propagation loss of the TM modes, a 200-nm-thick SiO$_2$ buffer layer was deposited on the surface prior to electrodes. The latter were fabricated by dry etching from a 1-μm-thick evaporated aluminum film.We first characterized the tuner itself, using the spontaneous emission spectrum of the optical amplifier as a broadband source. A mode conversion voltage was applied to the tuner and optimized for maximum conversion efficiency i.e., until a maximum of transmission is observed, that was obtained with $V_{MC} = 31$ V. The conversion efficiency was measured to be 98.5% and the loss of the pigtailed tuner was of 5 dB. The peak wavelength thus obtained was $\lambda_o = 1543$ nm at room temperature and the linewidth at FWHM was $\delta\lambda = 0.7$ nm. The slight deviation from the theoretical centre wavelength of 1542 nm may be attributed to fabrication tolerances in both the mode birefringence and electrode period. It can be compensated by temperature tuning [10] or by applying a bias tuning voltage $V_T = 15$ V to center the pass wavelength at 1542 nm. Then the fiber laser was tested. Due to the isolator, the laser is a travelling-wave ring laser and the optical power is provided by only one output port of the coupler. Without and with the tuner in the loop, the laser threshold was obtained with a 4-dB and 10-dB gain, respectively. This increasing is due to the 5 dB loss introduced by the tuner. The total loss for a single trip in the loop is estimated to be ~7 dB. Wavelength tuning was carried out with the amplifier gain adjusted at 18 dB, well-above the laser threshold, and with an emitted optical power of 0.2 mW. Fig. 2 shows typical emission spectra thus obtained as a tuning voltage V_T is applied, indicating a -30 dB side mode suppression. The laser linewidth was estimated to be smaller than 100 kHz, using a delay heterodyne spectrum analyzer. However, the lasing mode is unstable and hops inside a range of about 0.06 nm. Such a linewidth is 50 times narrower than that obtained (3 nm) with previous electrooptic birefringent tuners used in fiber lasers. The laser can be tuned between 1537 nm and 1547 nm with a tuning rate of 0.05 nm/V. In the present device, the 10 nm tuning range was limited by the ±100 V breakdown voltage of the tuning electrodes.

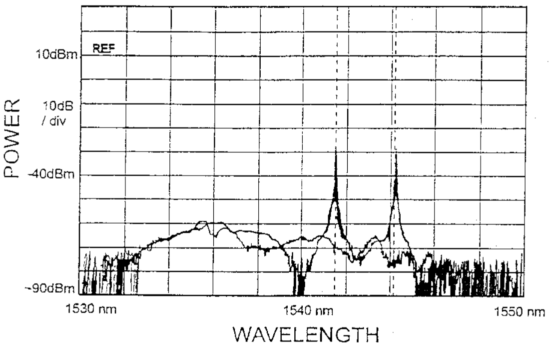
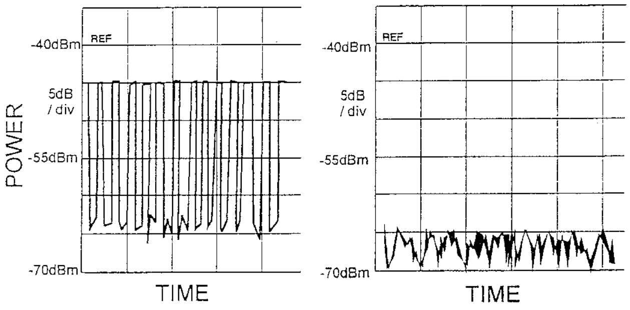


Fig. 2. Emitted power-spectra for two different tuning voltages $V_T = 21$ V and 85 V (horizontal axis: 2 nm/div, vertical axis: 10 dB/div).



(a) (b)

Fig. 3. Emitted power versus time as the laser is intensity-modulated and tuned at $\lambda = 15430$ nm. (a): signal detected at $\lambda = 15430$ nm; (b): signal detected at $\lambda = 15430.2$ nm (horizontal axis: 80 ms/div, vertical axis: 5 dB/div).

In order to check the potential use of the laser for high density wavelength division multiplexing, we modulated the mode conversion voltage V_{MC} between 17 V and 31 V to obtain on-off keying. As an illustration, in Fig. 3(a), the laser is intensity-modulated (via V_{MC}) with the operating wavelength tuned at $\lambda_1 = 1543$ nm (via V_T). Crosstalk at $\lambda_2 = 1543.2$ nm is measured to be -20 dB, using a spectrum analyzer with a 0.1 nm resolution [Fig 3(b)]. This is physically due to side lobe levels attached to the transmission peak of the filter, whose shape obeys approximately a sinc^2-function. Hence, the laser can be potentially used to route 50 0.2 nm-linewidth wavelength channels for WDM transmissions. Although the electrical bandwidth is limited here to 25 kHz, it can be anticipated that ~100 MHz are possible using thicker convertor electrodes. The wavelength switching time is related to the electrical bandwidth of the tuning electrodes, that was of 20 MHz in the present device. It can also be increased up to ~200 MHz using thicker tuning electrodes.

In conclusion, we have demonstrated a narrow linewidth fiber ring laser tuned electrically using an integrated TE-TM convertor.The wavelength switching time is of 50 ns and the laser linewidth is of 0.06 nm, 50 times narrower than that previously reported with birefringent tuners. It seems to be the best performance achievable with present time $LiNbO_3$ technology.

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