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23-channel with 100-GHZ spacing multi-wavelength laser source

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Abstract. Simultaneous oscillation of 23 wavelengths, spaced at 100 GHz, is demonstrated from a stable semiconductor optical amplifier source. The wavelength comb is generated from a fiber Lyot filter and each wavelength has 12.5-GHz linewidth. [DOI: 10.1117/1.1536184]

Subject terms: lasers; semiconductor lasers; multi-wavelength laser; semiconductor optical amplifier.

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1 Introduction

Very high capacity dense wavelength-division multiplexing (DWDM) systems are of great practical interest. As the number of wavelength channels has continued to increase in these systems, the cost and complexity of transmitters is increasing because of the large number of individual laser diodes. To tackle these issues a number of alternative techniques for obtaining multi-wavelength operation from single laser sources have been investigated. Spectrum slicing has been applied successfully to LEDs, superluminescent diodes, amplified spontaneous emission from erbium-doped fiber amplifiers (EDFA's), supercontinuum generation in fiber, and femtosecond pulses.[1–4] Multi-wavelength oscillation has also been obtained in semiconductor optical amplifier (SOA) lasers that use intra-cavity gratings and Fabry-Perot etalons[5] and in a liquid nitrogen cooled erbium-doped fiber (EDF) laser with a Lyot-type comb filter resulting in 24-line operation.[6]

In the present communication we present a source that uses a SOA in combination with this type of filter to demonstrate simultaneous, 23-line operation from a single source at room temperature. The source has demonstrated 100-GHz line spacing, 12.5-GHz linewidth, 17-dB extinction between lines, and less than 3-dB maximum power variation between the lines. It was also possible to extend the number of oscillating lines to significantly more than 30 at the expense of extinction and power equalization between them.

2 Experiment

Figure 1 shows the polarization maintaining (PM) fiber filter. It consists of a length L of PM fiber, placed between polarizers aligned at 45 deg with respect to the birefringent axes of the PM fiber.

The different propagation constants for the two birefringent axes of the fiber result in a squared cosinusoidal filtering function:

$$T=\frac{1}{4}\left|\exp(-j\beta_x L)+\exp(-j\beta_y L)\right|^2=\cos^2\left[\frac{(\beta_x-\beta_y)\cdot L}{2}\right],$$

where β_x and β_y are the propagation constants through the axes of the PM fiber. The free spectral range of the filter is given by:

$$\delta\lambda_{\mathrm{FSR}}=\frac{B\cdot\lambda}{L},$$

where B is the beat length of the PM fiber.

Using commercially available PM fiber of 3-mm beat length, 5.77 m of fiber are required to construct a comb filter with 100-GHz line spacing. Distinguishing features of the filter that result from its cosine-squared transmission function are the low single pass finesse (2) but very high extinction at the center of the rejected wavelengths. The filter is attractive for wavelength comb generation in a laser cavity because it presents very low loss, it can be tuned easily and precisely to the comb spacing, and it is very simple to build. Finally the effective finesse of filtering may be enhanced by double pass in a linear cavity.

Figure 2 shows the linear cavity of the multiwavelength source formed between two dielectrically coated mirrors of 99% reflectivity. Gain was provided by a 500-μm, bulk InGaAsP/InP ridge waveguide SOA, with facets angled at 10 deg and antireflection coated. The device has a small signal gain of 23 dB at 1535 nm when driven with a 250-mA dc current. The SOA exhibited a 2-dB small signal gain polarization dependence between its transverse electric (TE) and transverse magnetic (TM) axes and polarization controllers were used on its ports for polarization control. Output from the source was obtained with a 5:95 fused fiber coupler. The wavelength comb-generating filter consisted of 5.77 m of PM fiber, followed on its left side by a polarizer and a mirror. It was found that the gain dependence of the SOA in conjunction with the polarization controllers could be used to achieve the comb-generating function of the filter. However, the use of a second polarizing element before the right side mirror may enhance the extinction by 5 dB in the troughs of the generated multi-wavelength signal.

3 Results and Discussion

With the polarization controllers and the right side polarizer adjusted to couple the oscillating signal in the high gain axis of the SOA and at 45 deg to the input of the PM fiber, the source displays multi-wavelength oscillation when

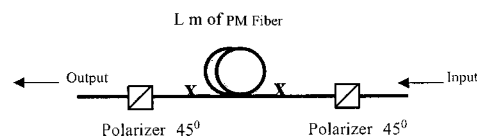

Fig. 1 The PM fiber, comb filter.

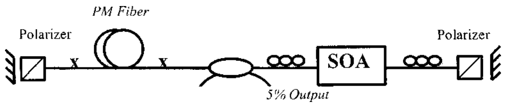

Fig. 2 Experimental layout of multi-wavelength laser.

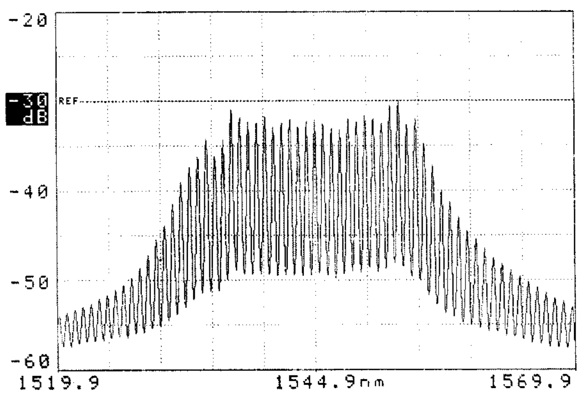

Fig. 3 Optical spectrum of the multi-wavelength laser.

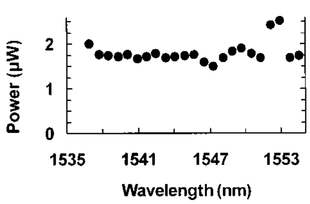

Fig. 4 Power distribution for output wavelengths.

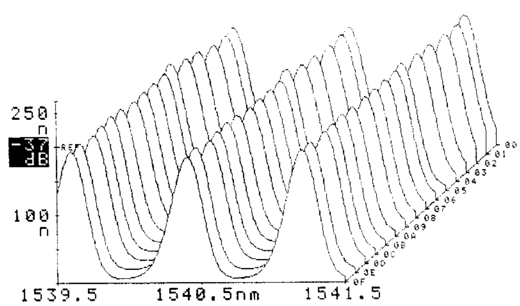

Fig. 5 Output time evolution over 90 min.

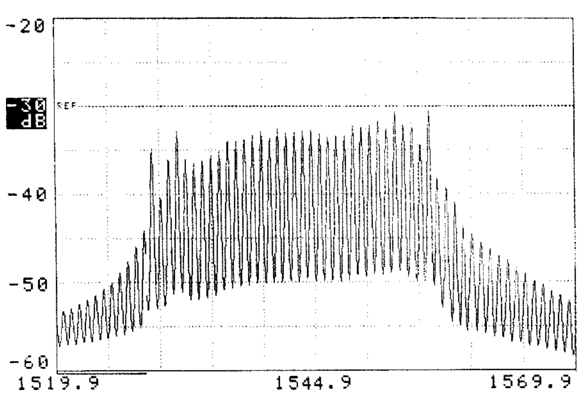

Fig. 6 Output with oscillation employing both SOA gain axes.

driven at maximum current. Figure 3 displays the optical spectrum and shows that 23 of the oscillating lines have less than 3-dB power variation between them and 17-dB extinction. The FWHM of each oscillating wavelength was measured with a high finesse fiber Fabry-Perot (FFP) filter and was found to be about 12.5 GHz. The total output power of the source was 42 μW and Fig. 4 shows the power distribution across the 23 most intense lines.

The stability of the multi-wavelength laser was also tested. Due to the relatively short cavity and strong polarizing properties of the cavity the output remains stable for hours in laboratory conditions. Figure 5 shows the 3-D temporal evolution of three lines from the profile. The figure is plotted linearly, covers a 90-min time span, and displays the good stability characteristics of the source.

It is possible to obtain oscillation in a larger number of wavelengths if the signal is coupled on both gain axes of the SOA, as shown in Fig. 6, which displays more than 30 wavelengths. The lower gain axis of the SOA (TM), oscillates at slightly shorter wavelengths, so that coupling into this allows extension of the oscillating spectrum toward shorter wavelengths. The lower gain value of the TM gain axis of the SOA compared to the TE results in a systematic slant of the output power across these lines, which however could be removed with an optical filter. It is expected that using a SOA with higher gain and lower polarization gain dependence will enhance the regularity, extinction, and number of oscillating lines.

4 Conclusions

In summary, we have demonstrated a simple and stable multi-wavelength source. It combines a semiconductor optical amplifier and a simple PM fiber filter that operates as a Lyot filter. The source has been shown to be capable to oscillate simultaneously at 23 wavelengths with less than 3-dB power variation across them. The oscillating wavelengths had 17-dB extinction and 12.5-GHz linewidth. The source can be used in laboratory DWDM transmission evaluation experiments and reduce substantially the cost of the transmitter.

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