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An optical multi wavelength oscillator based on fiber phase sensitive amplification

A. Gershikov*, G. Eisenstein

Department of Electrical Engineering, Technion, Haifa 32000, Israel

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ABSTRACT

We introduce a new concept for photonic components, an optical multi wavelength oscillator based on fiber phase sensitive parametric amplification. Two experimental setups were demonstrated, one for a continuous wave pump and the second for a pulsed pump. For each setup, several simultaneous oscillating lines were observed. The spectral spacing of the emitted lines and their power variance depend on the physical properties of the system as well as the pump wavelength. The pulsed pump setup also offers tunability over hundreds of nanometers with several simultaneous oscillating lines.

1. Introduction

Optical multiple wavelength generation is an important technique for many applications including multi wavelength optical communications [1], signal processing [2], RF photonics [3] and arbitrary waveform generation [4]. Common techniques to implement such multiple frequency sources are mode locked lasers [5], FM modulated CW lasers [6], regeneratively modulated sources [7], fiber ring cavities employing modulation instability [8] and cascaded four wave mixing by one [9] or two pumps [10]. All these techniques offer sources which have been used in experimental systems. Some, but not all of those guarantee phase locking of the various spectral lines which is often required.

In this work we introduce a different optical multi wavelength oscillator (OMWO) which is based on the cyclical nature of phase sensitive amplification (PSA) in optical fibers [11]. The cyclical gain refers to the fact that if a pump and a signal are injected simultaneously, the gain has periodic peaks and valleys for varying detuning between the two input signals. PSA is a well-known process having several advantages over conventional, phase insensitive parametric amplification (PIA), mainly a lower noise figure [12,13]. Similar to the research on PIA, most reported works on PSA concentrated on conventional broad band parametric amplification [14] where the pump propagates in the anomalous dispersion regime and exhibits a broad gain spectrum in the spectral vicinity of the pump. PSA can also make use of narrow band parametric gain as we have previously demonstrated [15]. In this mode of operation, the pump propagates in normal dispersion regime, and phase matching conditions are satisfied by a balance between dispersion parameters of different orders. Two parametric gain spectra are created in two narrow bands, spectrally placed far from the pump. Narrow band PSA exhibits a cyclical gain pattern [15] just as in the broadband case [16]. The major advantage of operating in the narrow band regime is the ability to reach wavelength regions not attainable with conventional (broad band) systems. When using a pulsed pump, we employ this advantage to generate a cyclical gain spectrum and a multi wavelength source. The periodicity of the gain depends on physical properties of the system, and pump-zero dispersion wavelength (ZDW) detuning. Two experimental setups were demonstrated and are reported in this paper, the first operating only in the broad band gain regime, with continuous wave (CW) pump. The oscillations are obtained in this case in the spectral vicinity of the pump, and the spectral spacing depends only on the system physical features. The second setup utilizes a pulsed pump, and operates in both the broad and narrow band gain regimes. While operating in narrow band mode, the oscillations are tunable over hundreds of nanometers, and the lines spectral spacing depends on both the system physical properties and the pump wavelength. This results in a situation where the line spacing is not constant across the operating wavelength range of the MWO.

2. Multi wavelength oscillator structure

A schematic of the CW multi wavelength oscillator we investigated is described in Fig. 1. The pump is a tunable laser

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* Corresponding author.
E-mail address: alexger@tx.technion.ac.il (A. Gershikov).

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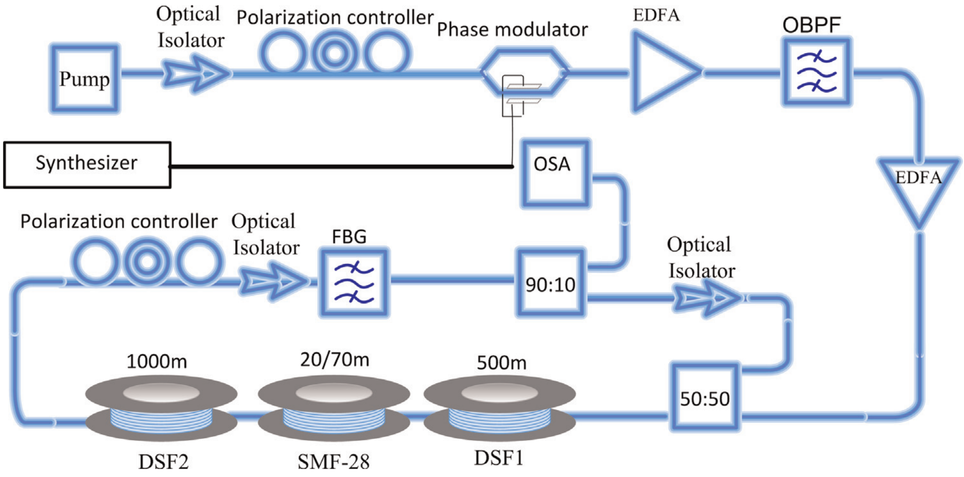

Fig. 1. Experimental schematic of a CW MWO.

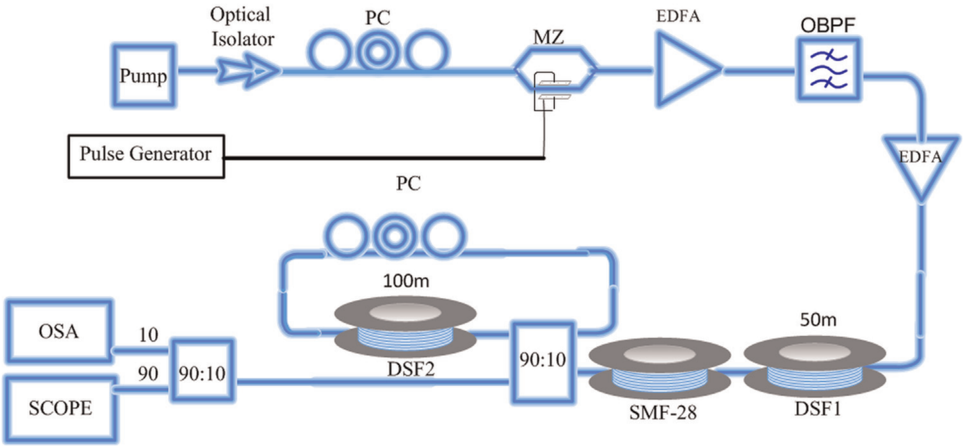

Fig. 2. Experimental setup of the pulsed pump MWO.

operating between 1530 nm and 1560 nm. It is phase modulated by a sinusoidal signal at 650 MHz in order to broaden its spectrum and therefore suppress Stimulated Brillouin Scattering (SBS). The pump is amplified in two stages to reach a typical power of 0.5 W. The amplified pump is coupled to stage one fiber, which is a highly nonlinear (HN), 500 m long, dispersion shifted fiber (DSF), with a zero dispersion wavelength (ZDW) of 1542 nm and a nonlinear coefficient $\gamma = 10$ $[\mathrm{W\,km}]^{-1}$. Here, conventional, PIA takes place and two waves: a signal and an idler are generated. Since no signal is applied to the system, the signal and the idler waves originate from amplified spontaneous emission (ASE). The three waves propagate in stage two fiber-a conventional (SMF-28) single mode fiber which de-phases the three waves before they are coupled to stage three which is a HN-DSF with dispersion properties similar to the one in stage 1. Stage 3 is 1000 m long. PSA takes place in the fiber of stage three resulting in a cyclical gain spectrum, with peaks at frequencies where the accumulated phases interfere constructively. The three fibers are placed within a ring cavity, therefore the oscillations experience both PIA and PSA gain. A polarization controller is placed within the cavity in order to control the mutual polarization of the pump and feedback waves. The cavity includes a fiber Bragg grating in order to filter out the pump after one pass in the cavity ensuring that only signal and the idler oscillates.

A schematic of the pulsed pump OMWO is shown in Fig. 2.

The pump is again a tunable laser operating between 1530 nm and 1560 nm which is now amplitude modulated by 4 ns width pulses at a repetition rate which synchronously pumps the cavity.

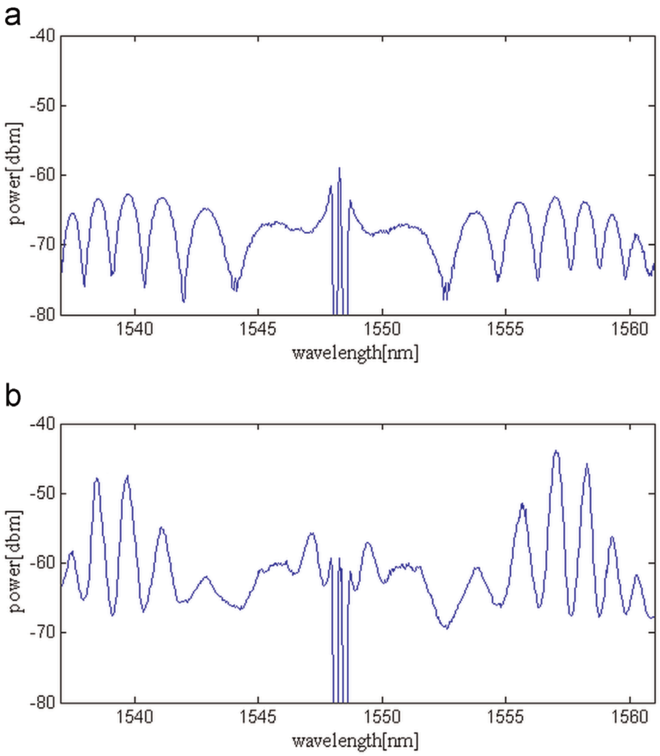

Fig. 3. Output spectra of (a) Open loop PSA with a CW pump and an intra-cavity filter. The dispersive fiber is 20 m long (b) MWO based on PSA with a CW pump.