EFFECT OF NOISE ON MODE-LOCKED HYBRID SOLITON PULSE SOURCE

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ABSTRACT

We describe the effect of spontaneous emission noise on mode-locked Hybrid Soliton Pulse Source (HSPS) utilizing linearly chirped and Gaussian apodized fiber Bragg grating. In this study, it is found that increasing noise cause pulsewidth suppression so that near transform limited pulses are not obtained.

I. INTRODUCTION

High power, narrow linewidth single mode lasers with low noise have many applications in lightwave systems, particularly as sources in externally modulated communications systems. The ability to produce these devices with tightly controlled operating wavelength is very important for many applications. The Hybrid Soliton Pulse Source (HSPS) is one such device, developed as a pulse source for soliton transmission systems. This device has demonstrated an extremely wide mode-locking frequncy range due to a novel wavelength self –tuning mechanism [1], which makes it very useful when price control over the operating frequency is required.

The realization of long distance soliton based transmission systems requires a reliable, stable source of transform limited pulses of the correct pulsewidth at the wavelenghth peak of an erbium-doped fiber amplifier chain. A practical system may operate at 2.488GHz with a pulse width of around 50 ps.

In this paper, we investigate the theoritical model of HSPS utilizing a linearly chirped and Gaussian apodized grating and the effect of spontaneous noise on this system.

II. THE MODEL

A schematic of the HSPS is shown in Fig.1. A 1.55 µm strained Multi-Quantum Well (MQW) laser diode is used, with one facet high reflectivity coated (HR) for improved cavity Q, and the other antireflection (AR) coated to allow coupling to the external cavity and suppress Fabry-Perot modes. The external cavity is composed of an AR coated lensed fiber and fiber Bragg grating. Active mode-locking is accomplished by applying a current waveform to the gain section, including a DC bias close to the threshold value plus an RF compenent that can be varied in amplitude and frequency.

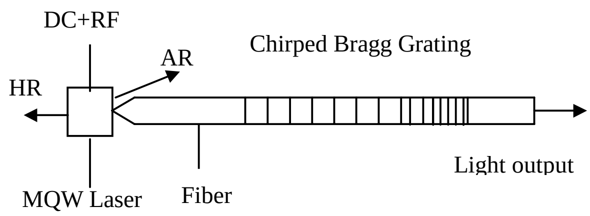

Figure 1. Schamatic of HSPS

The model is based on a time domain solution of the coupled-wave equations [2-3]. The variations of forward field *F(t,z) (+z direction)* and backward field *R(t,z)* (-z direction) can be found over a uniform cavity section using the transfer matrix method [4]. The laser cavity is divided into sections with equal effective length of Δz. For a time step $\Delta t = \Delta z / v_g$, the forward and backward fields are calculated from transfer matrix. In each laser section the carrier density is calculated from the rate equation:

$$\frac{dN(z,t)}{dt} = \frac{I}{eV} - \frac{N(z,t)}{\tau_n} - GS \qquad (1)$$

where I is the injection current, e is the electronic charge, V is the active layer volume, τ_n is the carier lifetime, and GS is the number of stimulated photons calculated in the coupled mode solution.

For each time step the new field values are calculated and boundary conditions applied. In order to calculate the progressive fields, either F_o *(z=0)* and R or R_o *(z=0)* and F are assumed to be known. Let us assume F_o and R are known, and write R_o and F in terms of these known fields:

$$\begin{bmatrix} F \\ R_o \end{bmatrix} = \frac{1}{\gamma\cosh(\gamma z) - (g_{net} - j\delta)\sinh(\gamma z)} \cdot \begin{bmatrix} \gamma & -j\kappa\sinh(\gamma z) \\ -j\kappa\sinh(\gamma z) & \gamma \end{bmatrix} \begin{bmatrix} F_o \\ R \end{bmatrix} + \begin{bmatrix} s_f \\ s_r \end{bmatrix} \quad (2)$$

Here g_{net} is the net field gain in the laser diode when the loss is subtracted from the gain, κ is the coupling factor, δ is the deviation from real part of propagation constant and $(\gamma^2=\kappa^2-\delta^2)$. s_f and s_r are the spontaneous noise coupled to the forward and reverse waves, respectively. They are assumed to have equal amplitudes [5], e.g.,

$$s(z,t) = s_f(z,t) = s_r(z,t) \quad (3)$$

Spontaneous emission is assumed to have a Gaussian distribution and to satisfy the correlation:

$$< s(z,t)s^*(z',t') >= \beta_{sp}\frac{R_{sp}}{v_g}\delta(t-t')\delta(z-z')$$
$$\text{and} \quad (4)$$
$$< s(z,t)s(z',t') >= 0$$

Here, $R_{sp} = BN^2/L_l$ is the electron-hole recombination rate per unit lenght contributed to the spontaneous emission. Here, B is the radiative (or bimolecular) recombination coefficient, L_l is the length of the lasing section, N is the carrier density, β_{sp} is the spontaneous coupling factor, and v_g is the group velocity of light in the cavity.

This process is repeated for a sufficient number of modulation periods to obtain stable mode-locked pulses.

MQW laser diode parameters are taken: Gain saturation parameter 2x10^{-17} cm^3, differential gain 10x10^{-16} cm^2, spontaneous coupling factor 5x10^{-5}, field coupling from laser to fiber 0.8, HR coating field reflectivity 0.9, AR coating field reflectivity 0.01, optical confinement factor 0.1, carrier lifetime 0.8 ns and internal loss 25 cm^{-1}.

III. RESULTS

In the simulation, a laser diode length of 250 µm and a grating length of 4 cm are used. The fundamental mode-locking frequnecy is chosen as 2.5 GHz and step size is 0.6875 ps. Applied DC bias and RF currents are 6 and 20 mA.

It is known that if the modulation frequency of a conventional mode-locked system is changed from the designed frequency, mode-locking cannot be established. HSPS can make mode-locking of the pulses for a wide frequency range available as mentioned in the beginning of the paper [1]. In order to deduce whether the HSPS is properly mode-locked or not, the field spectrum, output pulse intensity and their time-bandwidth products are examined. The transform-limit range is included in this work as time-bandwidth product that is in the range of 0.3 to 0.5.

Output power through the Bragg reflector, which is used as the output is shown Fig. 2(a) and (b). If the spontaneous noise is neglected, this result shows a pulsewidth of 45.38 ps and an optical spectrum of 8.68 GHz, giving a time bandwith product of 0.394 as shown the Fig. 2(a). Proper mode-locking range is observed between 2.2-3 GHz [6].

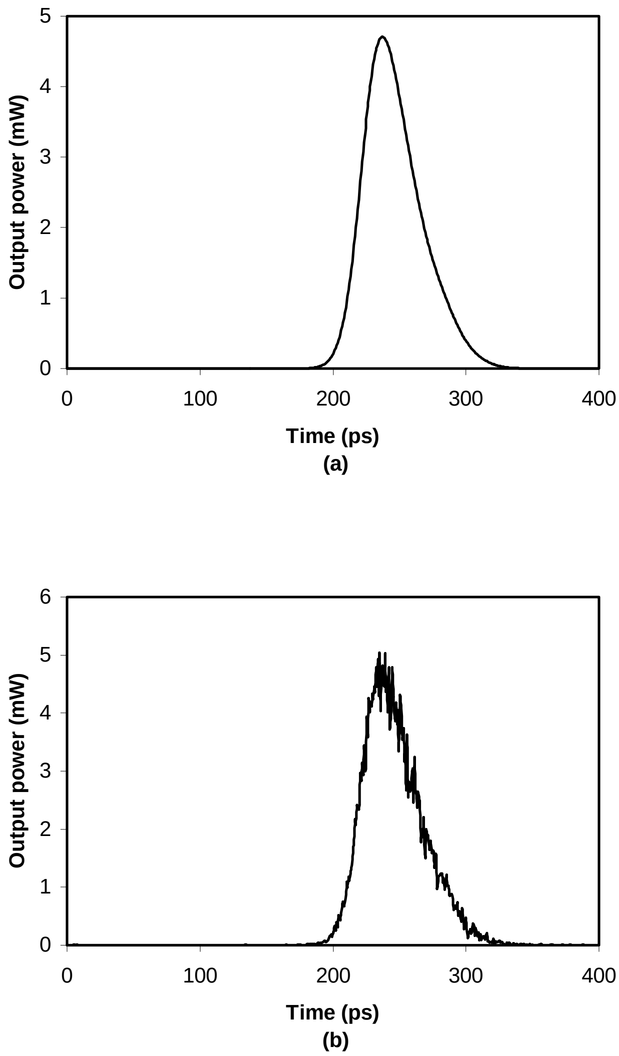

Figure. 2 Output intensity of HSPS; (a) without noise, (b) with noise

Effect of spontaneous noise on output is shown in Fig. 2(b). As seen the figure there are more ripples in the pulse. In this case, pulsewidth is 40.55 ps, optical spectrum is 8.67 GHz, time bandwidth product is 0.349

and mode-locking range is again 2.2-3 GHz. Reduction in the pulsewidth is the results of negative feedback due to stimulated emission modulating the carrier density tends to suppress amplitude fluctuations.

Increasing spontaneous noise cause high pulsewidth suppression and so not transform limited pulses are obtained. If spontaneous coupling factor is taken $20e^{-15}$ (for increasing noise), pulsewidth is 3.989 ps, optical spectrum is 8.987 GHz and time bandwidth product is 0.036. These results are not proper for practical applications.

Calculation of the relative intensity noise (RIN) versus frequency is shown Fig. 3, for same laser parametres and currents. A peak around 2.5 GHz shows optical resonance due to cavity roundtrip time. This frequency is the high noise level of the device, providing a low signal/noise ratio. This explain that why pulse suppression occurs at this frequency. As seen the figure, at the boundaries of the locking range, the RIN will rapidly increase.

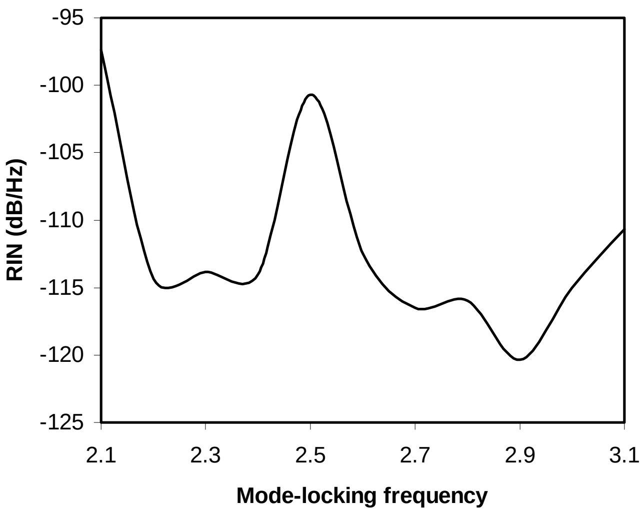

Figure. 3 RIN spectrum of the HSPS

IV. CONCLUSION

The main conclusion, near transform limited pulses are obtained over a frequency range of 800 MHz around a system operating frequency of 2.5 GHz and spontaneous noise does not affect these results if its value is low. But high noise affects the operation of device and transform limited pulses are not obtained.

It has been shown that at the resonance frequency RIN value is high as expected and pulse suppression occurs at this frequency.

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