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Performance analysis of wavelength conversion using a light-injected laser diode based on improved rate equations

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Abstract

The extinction and signal to noise ratios, the two main figures-of-merit for a wavelength converted signal are analyzed on the basis of the improved rate equations. The model accurately considers the mutual coupling parameter β_m which indicates the efficiency of the wavelength conversion. A simple relationship among extinction ratio, signal to noise ratio and the mutual coupling parameter β_m is given. With the simulation results, we find that the high extinction and signal to noise ratios depends on higher pump (i.e. original) power, optimum probe (i.e. converted) power and less wavelength spacing between them, which is in accordance with the analysis of mutual coupling parameter β_m.

Keywords: All optical wavelength conversion; Extinction ratio; Signal to noise ratio

1. Introduction

All optical wavelength conversion will be essential to avoid wavelength blocking and realize wavelength reuse and flexible management in WDM networks. But for practical use, it is preferable to allow arbitrary changing of the converted signal wavelength in WDM network, that is the incoming nonstandard information-bearing optical signal can be converted onto any standard and practicable wavelengths in WDM network. Various tunable wavelength conversion schemes have been reported, such as the wavelength converter based on a periodically poled $LiNbO_3$ waveguide [1,2], wavelength converter based on FWM in semiconductor fiber ring laser [3,4] and the wavelength converter based on fiber Bragg grating external cavity laser [5,6] (FBG-ECL). Among them, FBG-ECL is a potentially useful scheme. In this scheme, the laser oscillation is suppressed by external signal light injection, so it is expected to get higher extinction ratio and conversion efficiency compared to other schemes. On the other hand, it is convenient to change the converted wavelength by altering the reflection peak wavelength of the fiber Bragg grating through changing the stress or temperature of the fiber grating. This tunable wavelength converter enhances the capability of new network in which the information can be managed and routed very efficiently and flexibly. Some researches [7,8] based on such laser are reported. However, few theoretical studies [9,10] have been carried out, in which many optimal operating conditions for achieving the highest extinction ratio and SNR for the wavelength converted signal still remain unclear.

In this paper, we analyze the extinction ratio and SNR for the converted signal based on the improved rate equations of semiconductor laser. Our model takes into account the mutual coupling parameter β_m which indicates the efficiency of the wavelength conversion. The dependence of the extinction ratio and SNR on wavelength and power is investigated based on the model. The simulation results show that the extinction ratio and SNR of converted signal are determined by the mutual coupling parameter β_m intrinsically.

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2. Basic characteristics and experimental setup

Fig. 1 shows the experimental setup. An information-bearing (intensity modulated) signal centered at wavelength λ_p modulates the gain in the active layer of the FBG-ECL (continuous wave) where the process of gain saturation occurs. The intensity modulated signal and the continuous wave are also referred to as IM signal and probe signal, respectively. The intensity modulated signal and the continuous wave are also referred to as pump signal and probe signal. The CW signal at the required wavelength λ_c is modulated by the gain variation, so it carries the same information as the IM signal. In this system, the filter is used to remove injected signal λ_p.

The dependence of the converted light intensity on the input signal light power is discussed on the basis of the rate equations [11,12]

$$\frac{dN}{dt} = \frac{J}{ed} - \frac{N}{\tau_s} - v_g A_g (1 - \varepsilon S)(N - N_0)(S + \beta_m S_{in}) \tag{1}$$

$$dS/dt = v_g \Gamma G (1 - \varepsilon S) S - S/\tau'_p + \frac{\Gamma \beta_{sp} N}{\tau_e} \tag{2}$$

where N is carrier density, S is the photon density, J is the current density injected into the active layer, e is the electronic charge, τ_s is the carrier lifetime, $v_g = c/n$ is group velocity, Γ is the optical confinement factor, A_g is the gain slope constant, N_0 is the carrier density at which the net gain is zero, S_{in} is the externally injected photon density, ε is a small number (with units of volume) which specifies the gain compression characteristics of the active region, β_{sp} is fraction of spontaneous emission coupled into the laser mode, τ'_p is the equivalent photon lifetime, and β_m is the mutual coupling parameter which represents the conversion efficiency.

3. Derivation of the mutual coupling parameter β_m

Based on the rate equations and the definition of inversion population [13] (In the normal state of the semiconductor medium there are more atoms in the lower level than in the upper level, but when the medium is excited by an appropriate method so that the number of atoms in the upper lever is greater than the number in the lower level, the process is called population inversion, and the difference of atom number between the upper level and the lower level is defined inversion population.) in a four-level laser (the semiconductor laser can be considered basically as four-level lasers), we can obtain the expression of large-signal inversion population denoted by $\Delta n(v_1, I_{v1})$ when an IM light whose frequency and intensity is v_1 and I_{v1}, respectively is injected into the FBG-ECL.

$$\Delta n(v_1, I_{v1}) = \frac{\Delta n^0}{1 + \frac{\varphi_{v1}}{m_v(v_1)} g(v_1, v_0)} \tag{3}$$

where Δn^0 is the original reversal particle density, φ_{vi} is the photon density, $m_v = \frac{8\pi v^2}{c^3}$ is the density of single-color mode, $g(v_1,v_0)$ is the gain function, v_0 is the central wavelength of gain spectrum of the FBG-ECL.

When another light with frequency v_2 and intensity I_{v2} is also injected the FBG-ECL, the expression of inversion population is expressed by $\Delta n(v_2,I_{v2})$:

$$\Delta n(v_2, I_{v2}) = \frac{\Delta n(v_1, I_{v1})}{1 + \frac{\varphi_{v2}}{m_v(v_2)} g(v_2, v_0)} = \frac{\Delta n^0}{\left[1 + \frac{\varphi_{v1}}{m_v(v_1)} g(v_1, v_0)\right]\left[1 + \frac{\varphi_{v1}}{m_v(v_2)} g(v_2, v_0)\right]} \tag{4}$$

where $I_{vi} = \varphi_{vi} h v_i v$ $(i = 1, 2)$ is the light intensity,v_1 and v_2 can be seen as the frequency of IM signal light and the CW light, respectively, so we get the expression of mutual coupling parameter β_m:

$$\beta_m = \frac{\left(\frac{\Delta v}{2}\right)^2}{P_s} \times \frac{(v_1 - v_0)^2 I_{v2} + (v_2 - v_0)^2 I_{v1} + \left(\frac{\Delta v}{2}\right)^2 \left(I_{v1} + I_{v2} + \frac{I_{v1} I_{v2}}{I_s}\right)}{\left[(v_2 - v_0)^2 + \left(\frac{\Delta v}{2}\right)^2 \left(1 + \frac{I_{v2}}{I_s}\right)\right]\left[(v_1 - v_0)^2 + \left(\frac{\Delta v}{2}\right)^2 \left(1 + \frac{I_{v1}}{I_s}\right)\right]} \tag{5}$$

where Δv and I_s is the natural spectrum width and saturated light intensity of the gain medium, so for a fixed Δv and I_s, Eq. (5) shows that the mutual coupling parameter β_m is decided by intensity and frequency interval of CW light and the IM light.

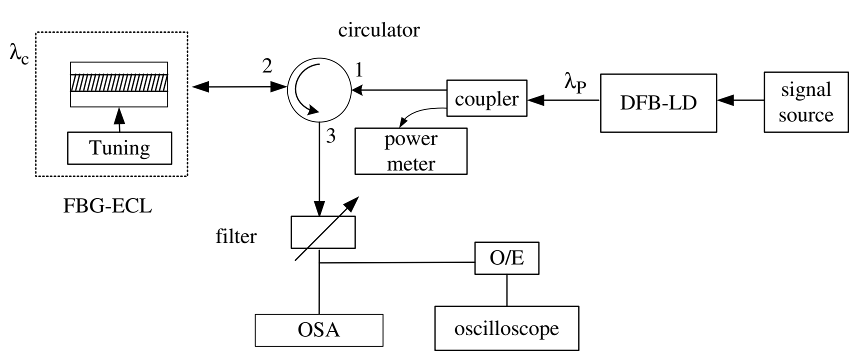

Fig. 1. Experimental setup for wavelength conversion.