Effects of Finite Gain Bandwidth on Raman Amplification in Silicon Waveguides

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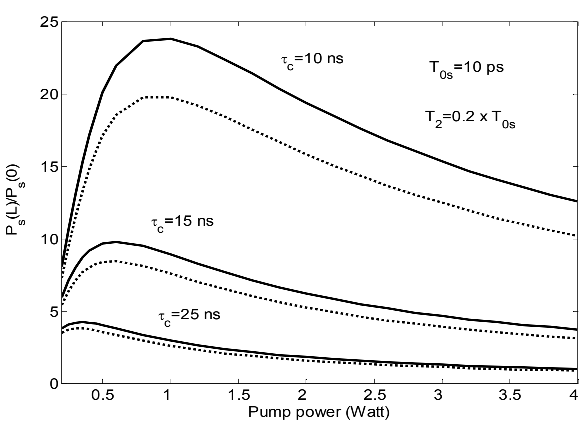
Abstract: The detrimental effect of gain dispersion on Raman amplification in silicon waveguides is studied by using a variational technique. The influences of finite gain and photogenerated free carriers are analyzed by introducing Rayleigh dissipation function.

OCIS codes (190.4400) Nonlinear Optics, Materials, (190.5650) Raman Effect, (160.2100) Electro-Optical materials.

Silicon waveguides are increasingly being used in recent years as Raman amplifiers and lasers [1-3]. However, a relatively narrow bandwidth of the Raman gain spectrum ($\Delta\nu_R \approx 100$ GHz) in silicon indicates that pulses shorter than 100 ps would suffer from gain dispersion, an effect that has not been investigated so far. In this work we focus on the effects of a finite Raman gain bandwidth on the amplified pulse. We consider a short signal pulse propagating through a silicon-on-insulator (SOI) waveguide under continuous-wave pumping. The frequency dependence of the Raman gain profile is approximated as $g(\omega) \approx g_R\left[1 - T_2^2(\omega-\omega_0)^2\right]$, where g_R is the Raman gain and T_2 = $(\Delta\nu_R)^{-1}$. The signal propagation through the SOI waveguide is governed by the following extended nonlinear Schrödinger equation [3,4] involving the free-carrier density N_c:

$$\frac{\partial E_s}{\partial z} + \frac{i\beta_2}{2}\frac{\partial^2 E_s}{\partial t^2} = ik_s n_2(1+ir)\left(|E_s|^2 + 2|E_p|^2\right)E_s - \frac{\sigma_s}{2}(1+i\mu)N_c E_s - \frac{\alpha_s}{2}E_s + \frac{g_R}{2}\left[1 + T_2^2\frac{\partial^2}{\partial t^2}\right]|E_p|^2 E_s$$

where we include the nonlinear effects such as self- and cross-phase modulations through n_2, two-photon absorption through r, free-carrier absorption through σ_s, free-carrier dispersion through μ, and linear losses through α_s. We solve this equation using a variational technique that assumes a Gaussian shape for signal pulses but allows all pulse parameters to change with z. We also make use of Rayleigh's dissipation function to account for all sources of signal gain and losses [5]. Using a standard procedure we derive a set of coupled differential equations for the four parameters (amplitude, phase, width, and chirp) associated with the pulse. We solve these equations numerically in the case of a 10-ps input Gaussian pulse. As an example, the solid curves in the Figure on left show the amplification factor as a function of pump power when the effects of gain dispersion are ignored. In contrast, dotted curves include the finite Raman gain bandwidth of silicon waveguides. The ratio of T_2 and pulse width (T_{0s}) is considered 0.2.



The role of carrier lifetime is explored by varying τ_c from 10 to 25 ns. As expected, a shorter carrier lifetime provides more gain. However, in all cases, gain dispersion reduced the realizable Raman gain.

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