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MODELING A DISTRIBUTED SPATIAL FILTER LOW-NOISE SEMICONDUCTOR OPTICAL AMPLIFIER

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We show using a beam propagation technique how periodic spatial filtering can reduce amplified spontaneous emission noise in a semiconductor optical amplifier.

Modeling a distributed spatial filter low-noise semiconductor optical amplifier

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A fundamental limit to the signal-to-noise ratio (SNR) obtainable in an optical amplifier is the amplified spontaneous emission (ASE) power coupled into the signal mode. It has been realized since the invention of the laser that ASE noise can be minimized by appropriate spatial filtering of the laser output: Since the signal occupies a much smaller solid angle than the isotropic noise, the noise can be limited by simply limiting the angular aperture at the output [1].

Using a geometrical ray model for the noise, the ASE power in a bandwidth $\Delta\nu$ into a solid angle $\Delta\Omega$ can be calculated from the formula [1]

$$P_{ASE} = \mu(G-1)\,A\frac{\Delta\Omega}{4\pi}\,h\nu\Delta\nu,$$

where $\mu = N_2/(N_2 - N_1)$ is the population inversion factor, G is the signal gain, $\Delta\Omega$ is the solid angle subtended by the system aperture, and A is the aperture area. However, this expression assumes that the gain of the ASE is equal to the gain of the signal. For a single-mode high-gain amplifier, this is a valid assumption, since the appropriate gain is just that of the propagating mode. For the case of low gain, many non-orthogonal modes are present, and the SE emission into the all the modes contributes to the noise power in the signal. This leads to the so-called "excess noise" phenomenon, whereby longitudinally inhomogeneous gain gives the appearance of more than one noise photon per mode when extrapolated back to the source [2].

A design for a low-noise optical amplifier was recently proposed which exploits the multimode transient phase of propagation in a SOA [3]. In this design, the gain region is divided into a number of sections, with free-space diffraction regions between them (see Fig. 1). We call this geometry

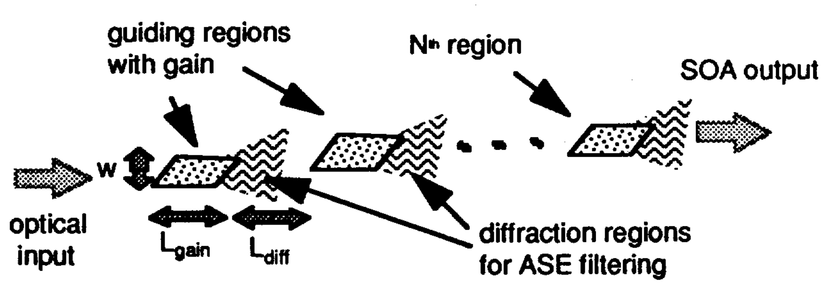

Fig. 1. Geometry of low-noise distributed spatial filter SOA

"distributed spatial filtering" (DSF). By keeping the gain-length product in each section small enough, the divergent ASE power is stripped before the single-mode state is reached and hence inhibits the ASE coupled into the signal mode. By distributing the spatial filtering using multiple sections, the stripping of the ASE occurs differentially for maximum effect.

To verify these ideas, we modeled the DSF low-noise SOA using a 2-dimensional FFT-based Beam Propagation Method, which solves a wide-angle paraxial wave equation. Spontaneous emission was treated as a randomly phased source throughout the laser. The amplitude of the SE was determined by demanding consistency between the paraxial equation and the radiation transport equation for the noise [4]. Observables such as field distributions and ASE power were calculated by ensemble average over realizations of the sources. Gain saturation was also included, although no detailed carrier dynamics was carried out.

In the following calculations we chose $L_{gain} = L_{diff} = 50\ \mu m$, $w = 3.5\ \mu m$, and $\lambda = 0.9\ \mu m$. The electric field intensity for a typical realization of the SE propagation is shown in Fig. 2. The diffraction of the ASE in the free-space regions is strikingly visible in this image.

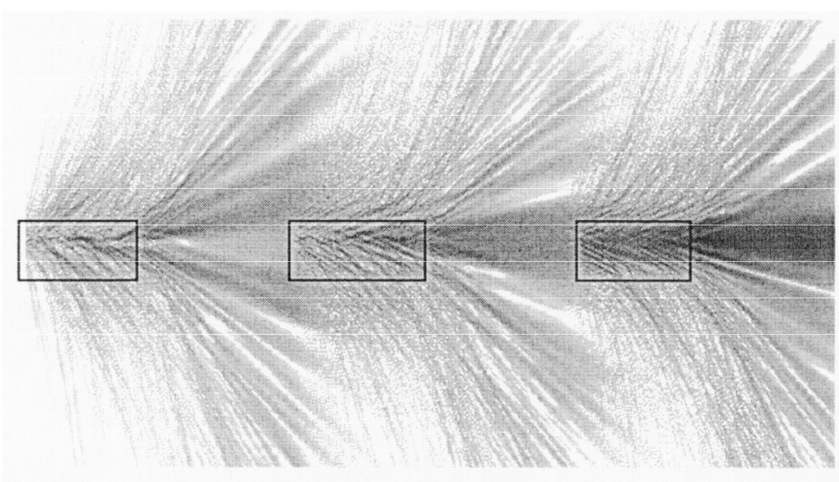

Fig. 2. Electric field intensity for three-stage DSF SOA

In Fig. 3, we compare the total ASE power as a function of the signal gain for a DSF SOA for 2 stages of filtering with a conventional SOA with the same gain-length product. We see that (1) there is a ~15 dB improvement in the ASE power for gains up to ~30 dB, and that (2) the improvement disappears for larger gains (60 dB). The latter observation reflects the fact that as mode selection due to propagation occurs, the multimode condition is lost. Next we look at the SNR (here taken as ratio of signal power to ASE power, valid for G>>1). Fig. 4 shows that there is an optimal value of the gain for two stage spatial filtering, by showing the ratios of the SNR's, for 2-stage DSF compared with no DSF.

Finally, if we plot the ratio of signal power to ASE power as a function of the number of DSF stages (Fig. 5), we see a sharp, possibly exponential, increase. This apparently verifies the differential nature of the effect. As the increase. This apparently verifies the differential nature of the effect. As the number of stages increases further, we would expect to see the improvement saturate as mode selection occurs in the SOA. Work is currently underway to optimize and fabricate the DSF SOA.

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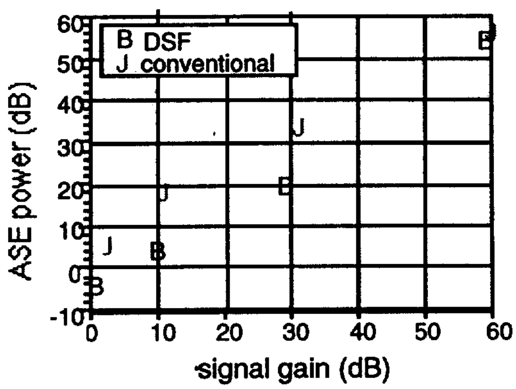

Fig. 3. ASE power vs. signal gain for a conventional and 2-stage DSF SOA

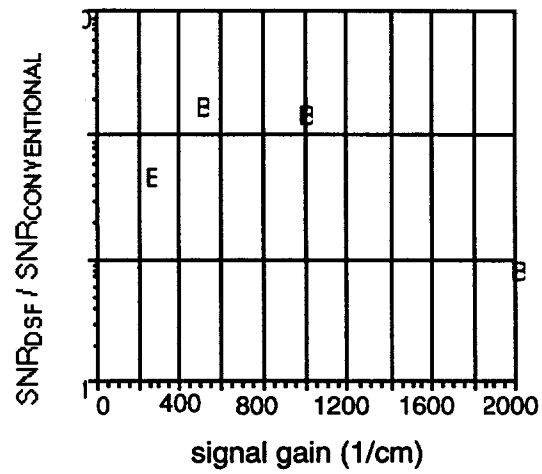

Fig. 4. Ratio of SNR's for 2-stage DSF to conventional SOA vs. signal gain

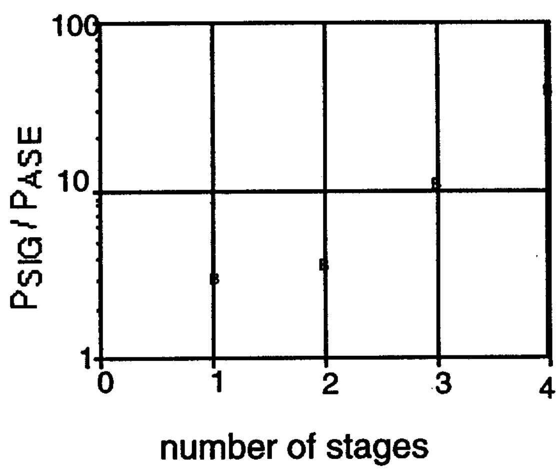

Fig. 5. P_{SIG}/P_{ASE} (SNR) growth with number of DSF SOA stages

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