Asymmetric waveguide design of laser diodes for pico-and nanosecond pulse generation in the eye safe spectral range: linear and nonlinear electromagnetic effects.

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High energy optical pulse generation using semiconductor lasers has attracted significant attention recently, for applications such as high-precision laser radars, three-dimensional time imaging, spectroscopy, and lifetime studies. Depending on the resolution required, pulses of either several to several tens of nanoseconds or ~ 100 picoseconds in duration can be required. In the former case, from the laser dynamics point of view, the laser is operating in a steady state with a transient at the start of the pulse; in the latter case, the main techniques used are gain switching (pumping the laser with a current pulse of a nanosecond duration or somewhat shorter, but still significantly longer than the desired optical pulse), active or passive Q-switching (using a laser incorporating an active voltage-controlled modulator or a saturable absorber respectively), or a combination of these techniques. In our recent work (see [1,2] and references therein), we have used gain-switched Fabry-Perot *asymmetric-waveguide* semiconductor lasers with a large equivalent spot size $d/\Gamma_a>>1\mu m$ (d being the active layer thickness and $\Gamma_{a,}$ the active layer confinement factor). A saturable absorber can be monolithically integrated within the laser cavity to facilitate high-energy afterpulse-free optical pulse emission in a broad range of injection current pulse amplitudes by combined gain- and Q-switching. Optical pulses with a peak power of about 35 W and a duration of about 80 ps at half maximum, without a substantial afterpulse structure, were achieved with a current pulse with an amplitude of just 8 A and a duration of 1.5 ns. Good quality, afterpulsing-free optical pulses were observed in a broad range of elevated temperatures. It has also been shown [3] that a similarly asymmetric laser structure, with a Quantum Well active layer, is advantageous for quasi-CW operation, emitting optical pulses in the range of a few nanoseconds to hundreds of nanoseconds long.

Until recently, our calculations and experiments centred on the case of GaAs/AlGaAs lasers operating in the spectral region of 800-850 nm. Currently, pulse emitting lasers operating in the eye-safe region of 1400-1700 nm are becoming increasingly important, for example for applications in laser radar technology. However obtaining high pulse power and energy within this spectral range is a more complex task than for shorter wavelengths, owing to higher optical and recombination losses, as well as the threat of current leakage into the *p*-cladding, in material systems capable of laser emission in this range. This is due to a combination of several effects. Firstly, the low hole diffusion coefficients in the OCL can lead to a high *inhomogeneously distributed* carrier density in the OCL, which leads to optical and recombination losses as discussed in [4,5]. Secondly, in some quaternary materials, the broad gain spectrum [6], particularly in narrow layers, increases the danger of carrier overspilling from the active layer to the Optical Confinement Layer (OCL) which increases the “background”, *homogeneously distributed,* carrier density in the Optical Confinement Layer (OCL). Thirdly, the optical losses are exacerbated by the high values of the Intervalence Band Absorption cross-sections by holes in III-V?? materials.

In order to keep the optical and recombination losses associated with the inhomogeneously distributed carriers low, while at the same time maintaining the large equivalent spot size value, we propose to use an asymmetric waveguide structure with an active layer located very close to the *p*-cladding, and to use in eye safe spectral range lasers a bulk active layer as first proposed in [7] for a GaAs laser, rather than the more commonly used Quantum Well based one. Either AlGaInAs/InGaAs or InGaAsP/InP material system can be used. The latter case is shown in Figure 1, which depicts a structure with $d/\Gamma_a \approx 3$ μm (d=0.08 μm, $\Gamma_a\approx0.0271$).

Figure 2 shows the rate equation simulation of the gain switching pulse generation in the structure under consideration. The maximum carrier density of $\approx 2.8 \times 10^{18}$ cm^{-3} in this relatively thick active layer ensures the electron and hole quasi Fermi level separation in the active layer well below the OCL bandgap, leading to low carrier overspilling and reducing the associated optical losses. In addition, the moderate carrier densities make for moderate Auger recombination in this structure which ensures a relatively low threshold current, making it easier to achieve the high output power generation with a modest pumping current amplitude.

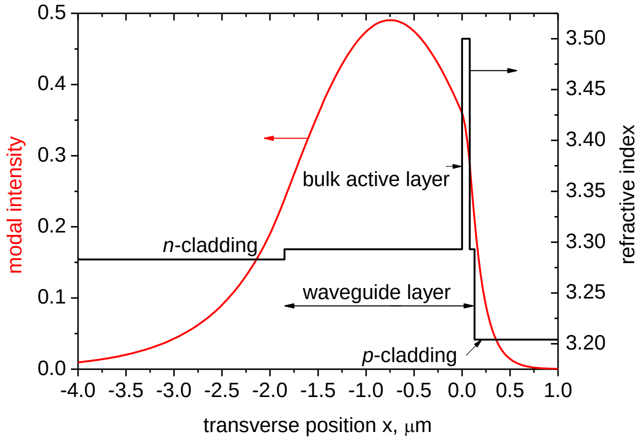

Figure 1. Structure under consideration and the corresponding modal intensity profile

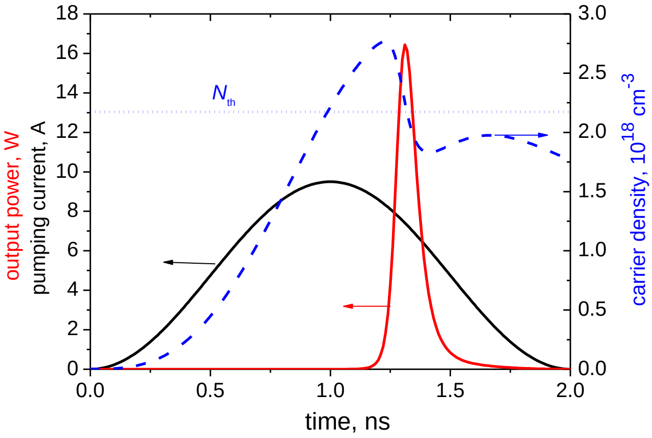

Figure 2. Simulated dynamics of gain-switching

The same structure, when biased by longer current pulses, is capable of generating high-energy nanosecond-range optical pulses in the quasi-CW regime of operation.

The use of the bulk active layer makes it also possible to introduce a simple saturable absorber, in the form of an unbiased section of the [2], further increasing the pulse peak power and potentially energy, and decreasing the afterpulsing structure.

Possible limitations to the optical power in both the picosecond and nanosecond regimes are related to both semiconductor properties (Auger recombination, current leakage and free-carrier absorption) and the nonlinear electromagnetic phenomenon of two-photon absorption, In particular, carrier accumulation in the waveguide due to two-photon absorption is predicted to be a noticeable limitation in the nanosecond regime, but considerably less so in the picosecond one.

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