Semiconductor e-h Plasma Lasers*

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Abstract: A new type of GaAs laser is based on the electron-hole plasma in a current filament and is not limited in size by p-n junctions.

* Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

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1. Introduction

High energy, electrically controlled, compact, short-pulse lasers are useful for: active optical sensors (LADAR, range imaging, imaging through clouds, dust, smoke, or turbid water), direct optical ignition of fuels and explosives, optical recording, and micro-machining. We present a new class of semiconductor laser that can potentially produce much more short pulse energy than conventional (injection-pumped) semiconductor lasers (CSL) because this new laser is not limited in volume or aspect ratio by the depth of a p-n junction. We have tested current filament semiconductor lasers (CFSL) that have produced 75nJ of 890nm radiation in 1.5ns (50W peak), approximately ten times more energy than ISL. These lasers are created from current filaments in semi-insulating GaAs and, in contrast to CSL, are not based on current injection. Instead, low-field avalanche carrier generation produces a high-density, charge-neutral plasma channel with the required carrier density distribution for lasing. We have observed filaments as long as 3.4cm and several hundred microns in diameter in our high gain GaAs photoconductive switches. Their smallest dimension can be more than 100 times the carrier diffusion length in GaAs. This paper will report spectral narrowing, lasing thresholds, beam divergence, temporal narrowing, and energies which imply lasing for several configurations of CFSL. It will also discuss active volume scaling based on recent high current tests.

2. Fabrication

Figure 1 shows our most stable CFSL. In this "surface-emitting" configuration, metal-coated, epitaxial contacts are grown on both surfaces of a semi-insulating GaAs substrate and 0.7-2.5kV is applied. A low-energy, short pulse of light initiates a straight current filament when a CSL is focused to a narrow stripe on the edge of the substrate, across the contacts. An image of the spontaneous radiation from a 40µm-wide, 1mm-long 20A filament is also shown in figure 1. The active region of the laser is this plasma channel between the contacts. Light exits the cavity through holes in the metallic layers on the surfaces which may be coated with metallic or dielectric reflective layers. The cavity length is limited by the substrate thickness. Other configurations include a lateral edge-emitting device with surface contacts and a lateral edge-emitting device with edge contacts. The highest optical output energy came from an edge-emitting surface contacted device.

3. Characteristics

Spontaneous and stimulated emission are shown in Figure 2 where an off-axis spectrum (spontaneous) is compared with an on-axis spectrum (stimulated). The spontaneous emission is ~50nm wide. The envelope of stimulated emission is ~5nm wide. The width of the peak stimulated emission at 898nm was 0.1nm. Beam divergence was 3 degrees for a 2.5 mm filament and 9 degress for a 0.5 mm long device (full angle, 1/e diameters). Output energy ranged from 5-30 nJ in 1-2 ns wide pulses (2-30 W peak) where the current ranged from 5-95 A in 6ns wide pulses. Temporal narrowing was evident in that optical pulse widths were shorter and independent of current pulse widths when varied from 6 to 15 ns. Thresholds to lasing are shown in figure 3, where optical output energy is plotted versus filament current for a devices with: 1) no reflective coatings, 2) a low reflectivity (R) coating on the back-side, 3) high R coating on the back-side and a low R coating on the front side. These data represent the highest energies observed at these currents with 0.5mm long lasers. Instabilities and inhomogeneities in current filament formation produce a range of output energies and a variety of spectra. Methods to improve device operation such as electrical and optical confinement will be discussed.

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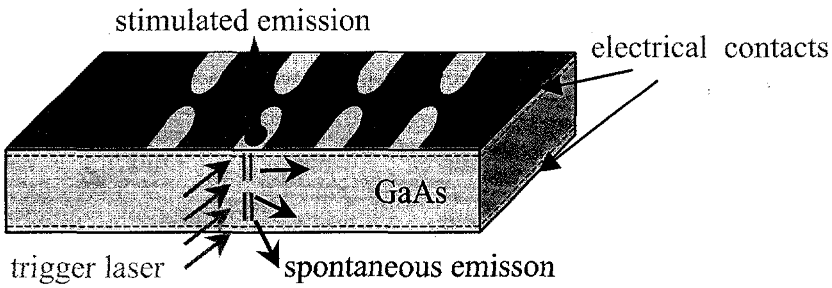


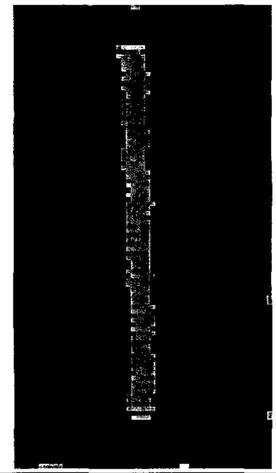
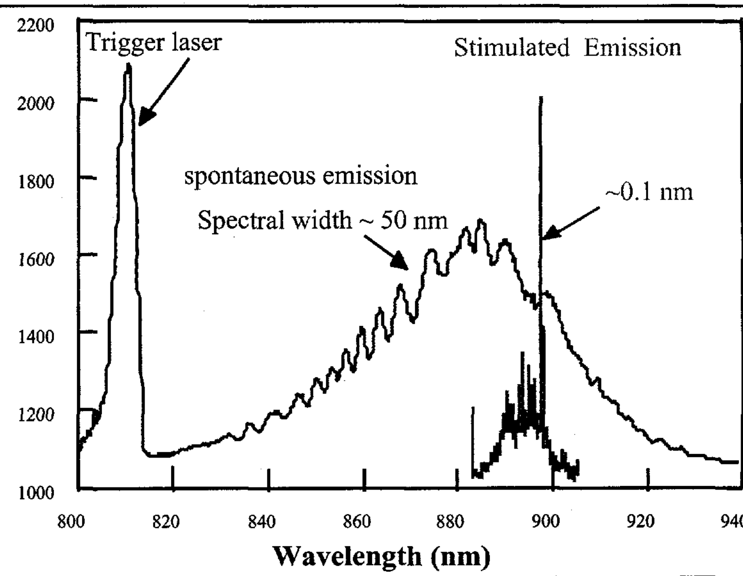


Figure 1. A low energy trigger laser initiates a current filament on the cleaved edge of the wafer. Avalanche carrier generation produces 3-5 orders of magnitude more carriers. Contacts and mirrors on both surfaces form a lasing cavity around the filament. The inset at the right shows an image of a line-triggered current filament (40 μm wide), the active region of the laser. No p-n junctions are required.

Figure 2. Comparison of off-axis spectra (spontaneous emission) and on-axis spectra (stimulated emission). The spontaneous emission is broad (~50 nm) due to the high temperature of the electron-hole plasma. The envelope of stimulated emission is ~5 nm wide because the carrier density in the plasma is very non-uniform. In this particular pulse, a very narrow peak (~0.1 nm) was produced at 898 nm. Spontaneous recombination radiation was used to make the image shown in the inset of figure 1.



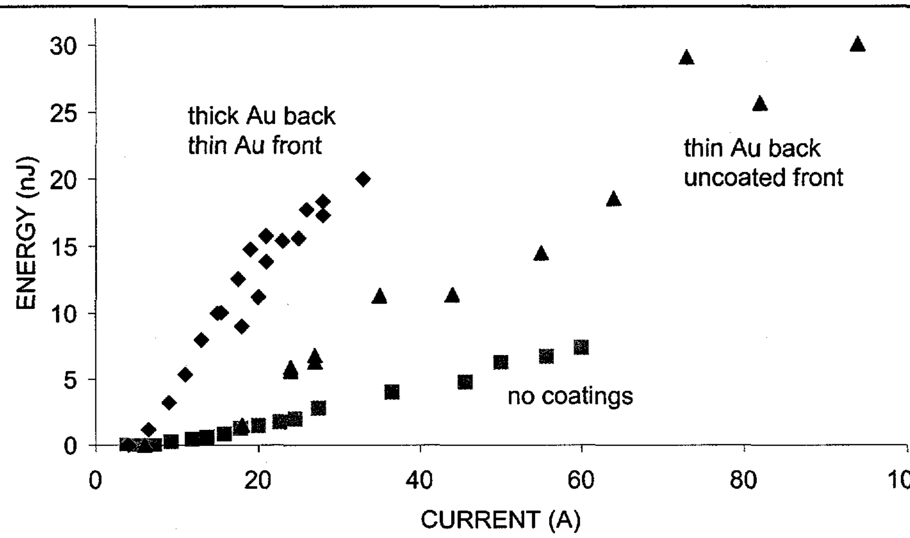


Figure 3. Lasing thresholds are shown in maximum optical output energy versus filament current. Filaments form at 5 A, but no optical output is observed. Data from the laser with the highest reflectivity coatings show the most increase with current, while data from the uncoated device show the least increase with current.