High-power 1.3 μm superluminescent diode

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Superluminescent diodes with high output power (10 mW at 175 mA), wide spectral width (28 nm), low spectral modulation depth ($< 15\%$), wide frequency modulation bandwidth (570 MHz), and high single-mode fiber coupling efficiency (40%) are reported. The structure is based on a buried crescent laser structure with an antireflection coating and a "short-circuit" absorber to suppress lasing.

Superluminescent diodes (SLDs) have desirable characteristics (such as elimination of modal noise in fiber systems, immunity to optical feedback noise, and high coupling efficiency into fibers) for use in many short and medium distance communication systems.[1] SLDs are also a key element in optical fiber gyroscope applications. The broadband characteristics of SLDs reduce Rayleigh backscattering noise, polarization noise, and the bias offset due to the nonlinear Kerr effect in fiber gyro systems.[2,3] In the last few years, high power (> 20 mW) GaAlAs SLDs (emitting at about 0.85 μm) have been demonstrated.[4–7] The reported output power of InGaAsP SLDs (emitting at about 1.3 μm) is typically less than 1 mW.[8–12] This is because SLDs usually operate at a high carrier density and InGaAsP has a higher nonradiative Auger recombination coefficient than GaAlAs. However, 1.3 μm SLDs are often more desirable than the 0.85 μm SLD due to a lower propagation loss and dispersion in optical fiber, and higher optical damage threshold in $LiNbO_3$ waveguide. 1.3 μm fiber optic systems also have a higher damage threshold under nuclear radiation. In this letter, we report a high-efficiency 1.3 μm SLD capable of emitting more than 10 mW power.

It has been shown that a GaAs-based SLD constructed from an index-guided laser structure can yield very high efficiencies based on tight optical and carrier confinement and a high spontaneous emission factor.[4,5] Such high efficiency will then be translated directly into device reliability under high-power operation. Here we demonstrate the fabrication of a 1.3 μm SLD using a design that is based on a proven high-power, high-efficiency index-guided buried crescent laser (capable of emitting greater than 30 mW into a stable index-guided lateral mode). Lasing is suppressed for the SLD operation by applying an antireflection (AR) coating on the emitting facet and by incorporating a rear absorber section. The resulting device emits optical power as high as 10 mW in the SLD mode at an injection current of 175 mA. The spectral modulation depth is below 15% over the entire emission spectral width of 28 nm, with a symmetrical beam divergence ($30° \times 40°$) and a stable transverse mode. The frequency modulation bandwidth is 570 MHz for a bias current of 140 mA.

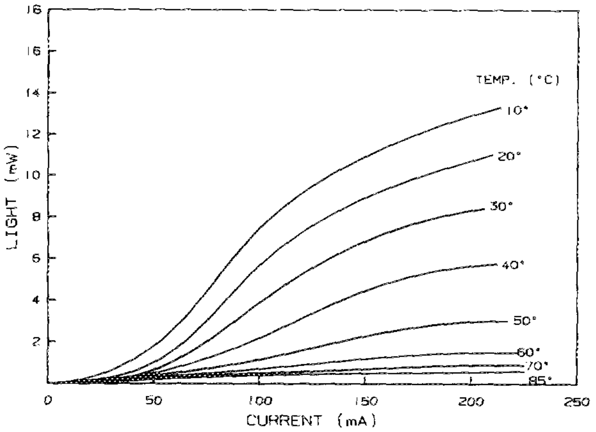

FIG. 1. cw light-current characteristic of the SLD at various temperatures.

The structure of the SLD is based on the buried crescent laser.[13] The buried crescent structure provides excellent current confinement, and therefore, low operating current. This real index guiding laser structure also provides stable single transverse output over a large range of operating currents. An antireflection coating on the output minimizes feedback to the cavity and therefore enhances optical output power from the front facet. An absorbing region at the back end of the active region absorbs radiation propagating away from the output end, thereby suppressing laser oscillation. The absorbing region is formed by shorting the *p-n* junction to ground in the rear section of the waveguide, so that the photoexcited carriers are "drained" to ground. This is a very efficient method, due to its wider absorption bandwidth, as compared to a single layer of antireflection coating (where the typical transmission bandwidth is only 20 nm). Typical device dimensions are: length of the pumped region $L = 730$ μm, the absorber region $l = 300$ μm, and the gap between the pumped and the absorber region $d = 25$ μm.

The cw light-current characteristics of the device at various temperatures are shown in Fig. 1. The device emits 10 mW for 175 mA injection current at 20 °C. The emission spectrum at 10 mW is shown in Fig. 2. The spectral width as

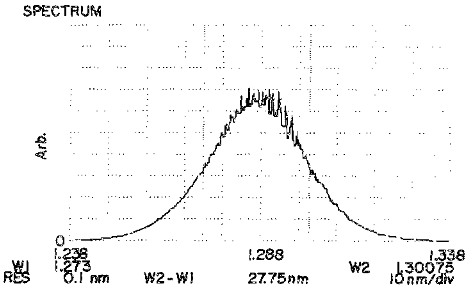

FIG. 2. Emission spectrum of the SLD at 10 mW, with a current of 175 mA, at a temperature of 20 °C.

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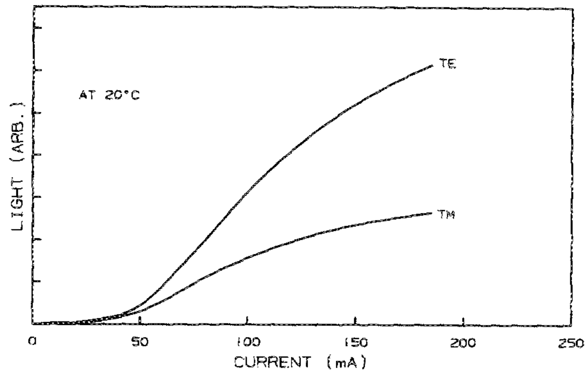


FIG. 3. TE and TM mode output power vs current.

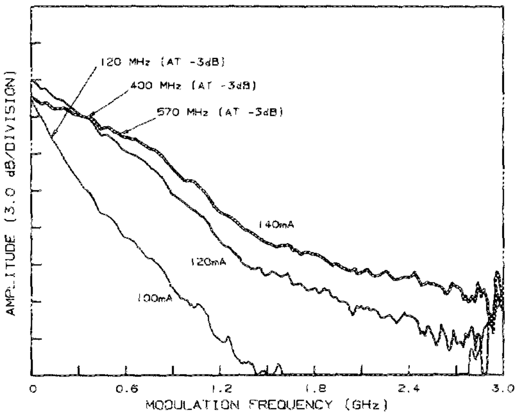


FIG. 4. Frequency response of the SLD at bias currents of 100, 120, and 140 mA, for a peak to peak modulation current of 4.5 mA.

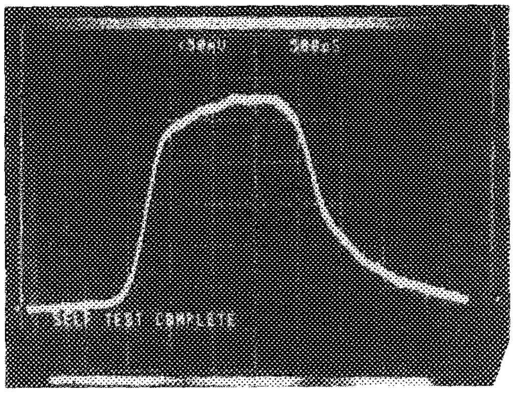
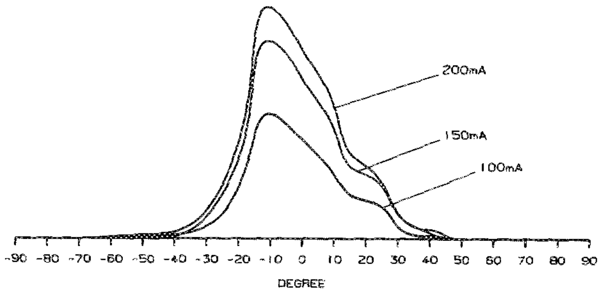


FIG. 5. Pulse response of the SLD at a bias current of 100 mA and a current pulse height of 6 mA.

(a) FAR FIELD PATTERN PARALLEL TO THE JUNCTION



(b) FAR FIELD PATTERN NORMAL TO THE JUNCTION PLANE

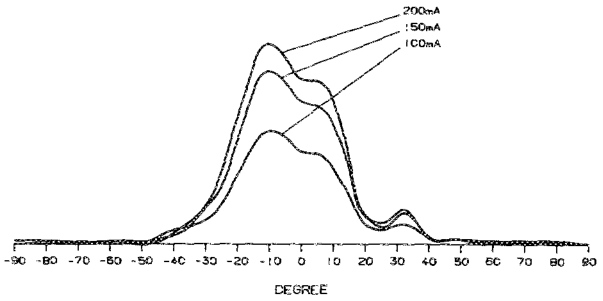


FIG. 6. Far-field intensity distribution of the SLD: (a) parallel to the junction and (b) perpendicular to the junction.

measured by full width half maximum is 28 nm. The estimated coherence length, $l_c = \lambda^2/\Delta\lambda$, is approximately 60 μm. The Fabry–Perot spectral modulation depth, defined as $m = (I_{\max} - I_{\min})/(I_{\max} + I_{\min})$, is less than 15%. The output for both polarizations versus current is shown in Fig. 3.

The frequency response of the SLD is shown in Fig. 4, where the SLD is biased at injection currents of 100, 120, and 140 mA, and the modulation current is 4.5 mA. The modulation bandwidth measured at the -3 dB points is 570 MHz at a bias current of 140 mA. Figure 5 shows the response of SLD under a 2 ns pulse excitation. The SLD was biased at 100 mA and the current pulse height was 6 mA. The rise time and fall time are 0.7 and 1.1 ns, respectively. These characteristics are suitable for use in transmission systems with a rate of several hundred megabits.

The far-field pattern of the SLD is shown in Figs. 6(a) and 6(b). The full widths at half maximum of the far field are 30° and 40° in the directions parallel and perpendicular to the junction plane, respectively. The far-field pattern shows smooth angular dependence which is another indication of the very low coherence of the SLD (the spatial resolution of the measurement system is 0.5°). There is no significant angular narrowing of the far field with increasing current, which suggests that the lateral mode behavior is dominated by real index guiding. The symmetric far-field pattern allows efficient coupling into a single-mode fiber with coupling efficiency as high as 40% having been demonstrated.

In conclusion, we have demonstrated high-power and high-efficiency 1.3 μm SLDs. The index-guided buried crescent structure yields very high efficiencies based on a high optical and carrier confinement and a high spontaneous emission factor. The short-circuit absorber design provides an effective means to suppress laser oscillation. Ths structure also produces a very symmetric, nonastigmatic output beam which facilitates coupling to single-mode fibers.

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