Interaction of a bistable injection laser with an external optical cavity

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Experimental results on interactions of a bistable laser with an external optical cavity are presented. Switching of a bistable injection laser can be done by varying the amount of optical feedback. The optical switching is accompanied by a switching of the voltage across the absorber section. This can be utilized in digital optical disk readout. A bistable laser with an antireflection coating on one facet is more suitable for this task. No pulsations can be observed in a bistable laser with optical feedback if the absorber section is biased with a constant current source; but when it is biased with a voltage source, pulsation occurs at the external cavity round trip frequency. This indicates that even though the intrinsic absorption of the semiconductor material does not saturate easier than the gain, the presence of such absorptions in GaAs lasers can still produce pulsations when the electrical aspect is taken into account.

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A bistable injection laser could find numerous applications in the field of optoelectronic signal processing. A simple way to realize such a device is to employ a double-contact structure which introduces inhomogeneous gain in the laser cavity.[1] Earlier work failed to produce lasers that exhibit hysteresis of useful size,[2–5] and moreover, these lasers were beset by pulsations in the optical output. Recently[6] we demonstrated, using an advanced laser structure (the buried heterostructure), a practical bistable laser with a large hysteresis and *no* pulsations. A negative differential resistance, reminescent of a tunnel diode, was measured across the absorber section of this double-contact laser, and with an appropriate electrical bias circuit (a large source impedance driving the absorber section, i.e., a current source) can result in a large hysteresis in the light-current characteristic without pulsations. There is, however, a second regime of operation under a different choice of biasing (a small source impedance at the absorbing section) which forces the device to operate in the unstable region of negative resistance. The negative resistance itself is not frequency selective and the device will pulsate at the resonance frequency of a frequency selective mechanism coupled to the negative resistance—the intrinsic relaxation oscillation of the laser.[7]

In a pair of recent papers we have described the static[6] and the dynamic electrical switching characteristics[8] of a bistable injection laser. Here we shall address its interactions with an external optical cavity. We have found that when the double-contact laser is operated in the bistable regime, the hysteresis shifts in the presence of optical feedback. This effect enables the bistable laser to be used as an integrated source detector element in digital optical disk readout, with performances superior to that obtained from ordinary injection lasers.[9,10] It was found that a bistable injection laser with an antireflection coating is more appropriate for this task.

Figure 1 shows the experimental arrangement and a typical hysteresis in the light *vs* I_1 (I_1 = current through the gain section) characteristics at a constant I_2 (I_2 = current through the absorber section). The laser used was a buried heterostructure laser described in our previous work.[11] The laser was not antireflection coated. The shift in the hysteresis under optical feedback is apparent. (In this case, the external feedback caused a lowering in lasing threshold from 22 to 19 mA, when both sections are pumped equally. The fraction of

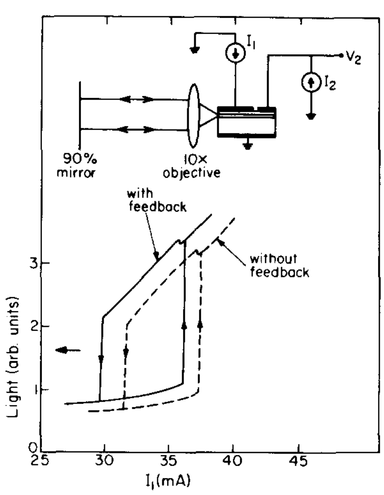

FIG. 1. Schematic diagram of the experimental arrangement (top). Measured light vs I_1 hysteresis with (dashed line) and without (solid line) optical feedback. The amount of feedback in this case is about 60%. $I_2 = -110$ μA.

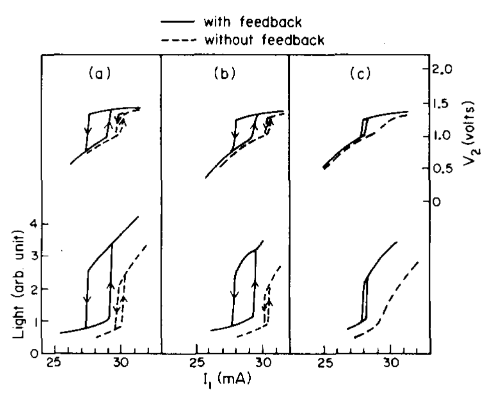

FIG. 2. Light vs I_1 characteristics where the hysteresis curves with (solid) and without (dashed) optical feedback do not overlap. (a) $I_2 = -80\,\mu$A, (b) $I_2 = -70\,\mu$A, (c) $I_2 = -60\,\mu$A. The amounts of feedback in (a)–(c) have an identical value of approximately 60%.

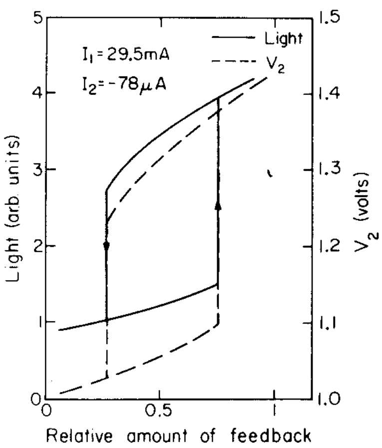

FIG. 3. Hysteresis in the light vs feedback and V_2 vs feedback (V_2 = voltage across the absorber section). The amount of feedback shown is only relative and a value of 1 corresponds to about 50–60%.

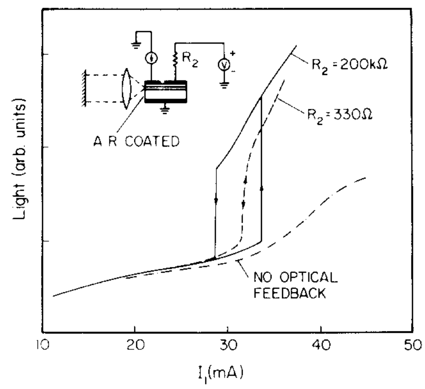

FIG. 5. Light vs I_1 characteristic of an antireflection coated laser with (solid and dashed lines) and without (dot-dashed) optical feedback. Dashed line shows the case when the source impedance R_2 at the absorber section is small.

light fed back into the laser is estimated to be around 50–60%). To switch the bistable laser on *and* off by varying the optical feedback, it is necessary that the hysteresis curves, with and without feedback, do not overlap. Since the amount of shift of the hysteresis is relatively small even with a fairly large feedback, one needs to decrease the size of the hysteresis. This can be done by increasing I_2, the pump current through the absorber section (i.e., making it less negative). The I_2's are -85, -75, and $-65\ \mu$A in Figs. 2(a)–2(c) respectively. Biasing the device at a value of I_1 between the dashed (without feedback) and solid (with feedback) light output hysteresis curves in Fig. 2 makes possible switching by purely optical means, as shown in Fig. 3. The voltage V_2 measured across the absorbing section depends on the feedback in a manner similar to that of the light output, as shown in Figs. 2 and 3. Switching the voltage V_2 by varying the amount of feedback can be utilized in optical disk readout, in which a rotating disk, carrying digital information as reflective spots, is placed in the feedback optical path. The bistable laser serves as an integrated source detector combination.

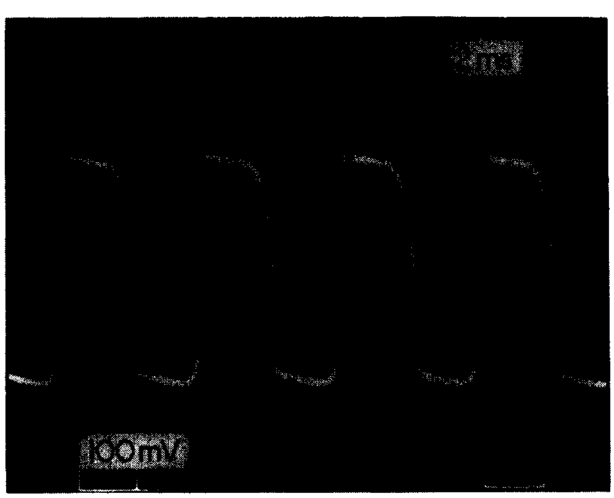

FIG. 4. Measured signal voltage V_2 at the absorber section contact due to a rotating chopper disk in the optical feedback path. Hor: 2 ms/div, Ver: 100 mv/div.

This application is simulated by inserting a chopper in the external cavity. The measured voltage V_2 is shown in Fig. 4. The slow rise (or fall) in the voltage preceding the fast switch-on (or switch-off) is caused by the finite traversal time of the chopper blade through the optical beam. The switching time is measured to be less than 70 ns, consistent with that obtained by electrical switching[8] of this bistable laser. Faster switching (<20 ns) can be obtained electrically by raising the switching pulse overdrive, an option not available in optical feedback switching. Critical slowing down similar to that in electrical switching,[8] of up to several microseconds, occurs when the amount of feedback is just barely sufficient to cause switching. Employing a bistable laser for optical disk readout, in addition to immunity from errors caused by noise fluctuations, gives a signal of several hundred millivolts, compared to a few hundred microvolts obtained with a common laser.[9,10]

One expects a larger flexibility in controlling the amount of feedback if a facet of the bistable laser is antireflection (AR) coated. Indeed, such a laser would barely lase even at fairly high currents and would not operate as a bistable laser (dot-dashed line in Fig. 5). Optical feedback restores the bistable behavior of the laser, as shown in Fig. 5 (solid line). Unlike the previous cases with no AR coating (Fig. 2), it is unnecessary to restrict the size of the hysteresis, or to maintain the bias current I_1 within a small range (between the dashed and solid curves in Fig. 2). The observed suppression of bistability with decreased mirror reflectivity and its enhancement with increase optical feedback are in agreement with calculations taking into account the superluminescence inside the bistable laser.

The above results were obtained with a bistable laser operated in the bistable regime (by driving the absorber section with a high impedance current source.) As mentioned above, when the absorber section is driven with a low impedance (voltage) source, the laser operates in a second regime where the device exhibits pulsation and only a small hysteresis. Without optical feedback, the electrical (and optical) pulsation occurs at the intrinsic relaxation oscillation frequency of a laser. With optical feedback the external cavity becomes the dominant frequency selective element and the laser is observed to pulsate at the round trip frequency of the external cavity. *Note* that such pulsations *do not* occur when the absorber section is driven by a *current* source, in marked contrast to the results obtained using aged or damaged lasers.[12–14] These results indicate that the intrinsic absorption of the semiconductor material does not satisfy a required condition for pulsation to occur, namely, that the absorption must saturate easier than the gain.[15,16] This condition was derived assuming that the absorbing and the gain regions are electrically isolated.[17,18] However, in the presence of electrical interactions, the above condition is no longer a necessary one for pulsation. The dashed line in Fig. 5 shows the light *vs* I_1 characteristic of an AR coated laser operating in the pulsation regime under optical feedback. Near the light jump, detector limited (150 ps) optical pulses at a repetition rate corresponding to that of the external cavity (600 MHz) can be observed. The pulsation is fairly stable, having a linewidth of less than 20 kHz as observed on a microwave spectrum analyser. The fact that the occurrence of these pulses depends on external circuit elements indicates that these pulsations are not produced solely through the mechanism of conventional passive modelocking (which requires a sublinear gain dependence on inversion density[18]), but is optoelectronic in origin, and that they are projected to be limited to a few GHz due to the finite bandwidth of the negative resistance (similar to a tunnel diode oscillator).

In conclusion, switching of a bistable injection laser can be achieved by varying the amount of optical feedback. The associated switching in the voltage across the absorber section can be ultilized in digital optical disk readout. A bistable laser with an AR coating on one facet is more suitable for this task. No pulsations can be observed when the absorber is current driven, indicating that in the absence of other side effects such as local heating,[19] the intrinsic absorption of GaAs does not saturate easier than the gain and therefore cannot produce pulsations through the mechanism of repetitive Q switching. The presence of these absorption centers can, however, produce pulsations through a different mechanism involving the electrical aspect of the device.

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