Self-propulsion Operating Regime for the Absorber of a Twin Section Laser Diode

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the following simultaneous equations are obtained:

\[ c = -a \]
\[ T_1 = b + c \gamma_x \]
\[ T_2 = 1 + a + b \gamma_x + c \delta_x \]

These can be solved to give expressions for the model coefficients

\[ a = \frac{1 + T_2 - T_1}{1 + \gamma_x - \delta_x} \] \[ b = \frac{T_1(1 - \beta_x) + \gamma_x(T_2 - 1)}{1 + \gamma_x - \delta_x} \]

Eqs. 11 and 12, when inserted into eqn. 1, provide a quadratic model for the depth-dependent lateral variance.

**Results and conclusions:** The equations for \( a = -c \) and \( b \) above are identical to those derived by Lorenz et al., except for the presence of a factor 1 before each of their equations. This factor derives from their perturbation approach. Figs. 1 and 2 show depth-dependent lateral spread profiles, predicted using mixed moments, for B and As ions, respectively, (implanted into amorphous silicon at energies 25, 100, 200, and 300 keV). The figures show the results obtained using the exact eqns. 11 and 12 together with results obtained using the approximate equations of Lorenz et al. Both sets of results are compared with high resolution Monte-Carlo data generated using a parallel processor version of the TRIM Monte-Carlo code written at the University of Kent. The exact equations provide fits which are perfectly adequate for most applications.

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**SELF-PULSATION OPERATING REGIME FOR ABSORBER OF TWIN SECTION LASER DIODE**

**Indexing terms:** Semiconductor lasers, Lasers and laser applications

The voltage–current characteristic of the absorber of a twin section laser diode is investigated as a function of the gain section current. For self-pulsation to occur the absorber must be operated within a specific region of the voltage–current characteristics. This region only exists for absorber voltage–current characteristics which contain an S-shaped negative resistance.

**Introduction:** To achieve higher operating speeds in telecommunications for both transmission and switching the use of optical devices rather than electronic devices has been proposed. Recently a useful application of self-pulsation in semiconductor laser diodes has been demonstrated by the use of a self-pulsating multielectrode laser diode \(^6\) for optical timing recovery. The conditions for self-pulsation in a twin section device have been investigated \(^5, 6\) and it has been shown that reverse bias can promote self-pulsation by reducing the effective carrier lifetime in the absorber.
The electrical characteristics of the absorber have also been investigated by Harder et al., who have proposed that at the onset of lasing there is a significant increase in the value of the absorber current. This results in an N-shaped absorber voltage-current (V-I) characteristic which has been interpreted as a negative differential resistance that promotes self-pulsation at the relaxation oscillation frequency. The effective load resistance for the absorber was shown to be important if self-pulsation were to be observed. This load resistance is dependent on the parasitic resistance between the sections.

In this Letter a self-pulsation operating regime is defined within the V-I characteristics of the absorber section of a twin-section laser diode. An active load is used which both controls the absorber voltage and reduces dependence on the parasitic resistance between the laser sections. The self-pulsating regime exists only for gain section currents which produce a decrease in the value of the absorber current at threshold rather than an increase as observed by Harder et al. This decrease in the absorber current at threshold is shown to be consistent with an 'S' shaped V-I characteristic. It is also shown that within the self-pulsating regime it is not necessary to bias the absorber in a region of negative resistance to observe self-pulsation.

Experimental details: The laser diode used was a BTRL InGaAsP BH device operating at 1616 nm. The device length was 500 μm with a 4.1 gain to absorber section length ratio. The laser threshold when both sections were pumped with equal current densities was 24.5 mA. The device temperature was 20°C ± 0.1°C. Two such devices have been investigated, yielding very similar results. An AT&T Astrotec 115A APD with a bandwidth greater than 1 GHz was used to observe the laser diode output on a 1 GHz real-time oscilloscope.

Absorber control: The absorber of a twin-section laser needs to be considered as both a source and a load for an external circuit. The total absorber current is the sum of a conventional forward current and a reverse photocurrent. Normal voltage regulator designs are unable to cater for significant reverse currents and an active load was developed which presents a low impedance both as a source and as a load.

In this experiment the active load used provides both an accurate 0–2 V bias for the absorber and a 30Ω resistive load for the reverse photocurrent from the absorber. By adjusting the absorber voltage at a fixed gain section current the value of the forward current into the absorber and thus the absorption can be controlled.

A significant advantage of this technique is that the parasitic resistance between the sections of the laser is effectively in parallel with the much smaller resistance of the active load. This means that the dependence of the absorber V-I characteristic on the value of the parasitic resistance is virtually eliminated. For the two devices investigated the parasitic resistances between the sections were 178 kΩ and 19.4 kΩ, respectively.

Results: The V-I characteristic of the absorber section of the laser was measured for a range of gain section currents and is shown in Fig. 1. In this figure the voltage on the horizontal axis has been normalised to the absorber voltage at threshold. The absorber current is negative because the reverse photocurrent is larger than the conventional forward current. For gain section currents up to 65 mA, the absorber current increases negatively at threshold resulting in an N-shaped characteristic. Each point on this characteristic can be measured because of the use of voltage control and is consistent with an N-shaped negative differential resistance. For gain section currents above 65 mA the absorber current displays a discontinuous step to lower values at threshold. The actual shape of the V-I characteristic at this discontinuity cannot be measured under voltage control. However by placing a 178 kΩ resistor between the absorber and the active load with the voltage polarity reversed a pseudo current source was created. The true V-I characteristic was investigated and was found to be S-shaped. For clarity the V-I characteristic close to threshold for a single gain section current of 80 mA is shown in Fig. 2. It shows the V-I characteristic under voltage control and under pseudo current control.

Harder et al. have proposed that for gain section currents with an N-shaped V-I characteristic, self-pulsation may be observed if the absorber is biased so that its operating point lies within the negative resistance region. However, in this experiment for an N shape no self-pulsation was observed at any operating point. Self-pulsation was only observed for V-I characteristics which contained an S shape. The oscillogram in Fig. 3 shows the self-pulsation in time for a gain section current of 80 mA.

It was also demonstrated that to observe self-pulsation it was not necessary to bias the absorber at an operating point
**Si/SiGe MODULATION DOPED FIELD-EFFECT TRANSISTOR WITH TWO ELECTRON CHANNELS**

*Indexing terms: Semiconductor devices and materials, Silicon, Field-effect transistors*

Si/SiGe modulation doped field-effect transistors with a two-dimensional electron gas in a cap and in a regular channel, 10 nm and 40 nm underneath the gate, were realised. The bias dependent population of the channels is explained by means of the bandstructure. High extrinsic transconductances of 155 mS/mm for the upper channel and 80 mS/mm for the deeper channel were obtained. Significant device improvements due to source/drain contact implantation are demonstrated by comparison with simultaneously processed devices with alloyed contacts.

**Introduction:** Apart from an early realisation of n-channel Si/SiGe modulation doped field-effect transistors (MODFET), no results on this topic have been reported until now. Based on improved modulation doped Si/SiGe heterostructures now available, we have developed novel MODFets showing two activated two-dimensional electron gas (2-DEG) channels with source and drain defined by ion implantation. We present a model for the population of two channels and report on the improved device performance.

Si/SiGe layer sequences grown by molecular beam epitaxy (MBE) were used. On a p⁺-Si substrate, which was wet chemically precedent and thermally prepared in the MBE system, a 40 nm undoped Si buffer was first deposited at 550°C. A 300 nm Si₀.₆₈Geₐ₀.₃₂ relaxed buffer was grown at 450°C. The structure then follows the layer sequence, as shown in Fig. 1a, grown at 550°C. The regular 2-DEG channel is formed in the tensile-strained Si layer underneath the modulation doped SiGe. A second 2-DEG channel is principally provided by the Si cap layer above the selectively doped SiGe.

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**Summary:** We have investigated the V-I characteristics of a twin section laser diode. It was found that to achieve selfpulsation the device must be operated inside a specific region of the absorber V-I characteristic. This selfpulsation regime only exists for absorber V-I characteristics which contain an S shape rather than an N shape at threshold. It is not necessary to bias the absorber in a region of negative resistance to observe selfpulsation. An active load was used to control the absorber. Two similar devices were investigated with different parasitic resistances. For both devices very similar results were achieved confirming that the active load reduces dependence on the parasitic resistance.

**Acknowledgment:** The authors would like to thank M. J. Robertson of British Telecom Research Laboratories for providing the twin contact lasers used in this work and A. F. Strege of AT&T Bell Laboratories who provided the APD used.

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