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

Gerald Farrell
Dublin Institute of Technology, gerald.farrell@dit.ie

P. Phelan

Joe Hegarty

the following simultaneous equations are obtained:

$$c = -a$$
$$T_1 = b + c\gamma_z \qquad (10)$$
$$T_2 = 1 + a + b\gamma_z + c\beta_z$$

These can be solved to give expressions for the model coefficients

$$c = \frac{1 + T_1\gamma_z - T_2}{1 + \gamma_z^2 - \beta_z} = -a \qquad (11)$$

$$b = \frac{T_1(1 - \beta_z) + \gamma_z(T_2 - 1)}{1 + \gamma_z^2 - \beta_z} \qquad (12)$$

Eqns. 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.*,[7] except for the presence of a factor $\frac{2}{3}$ before each of their equations. This factor derives from their perturbation approach. Figs. 1 and 2 show depth-dependent lateral spread profiles, predicted

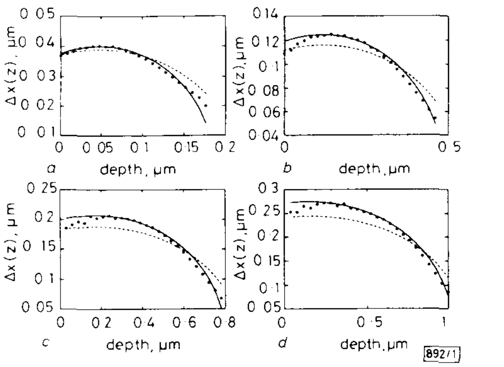

Fig. 1 *Predicted lateral spread profiles for B into a-Si using mixed moments*

a 25 keV
b 100 keV
c 200 keV
d 300 keV
• TRIM-85 (SCOEF88) Monte-Carlo data
——— Kent formulas using eqns. 11 and 12
- - - - Formulas from Lorenz *et al.*[7]

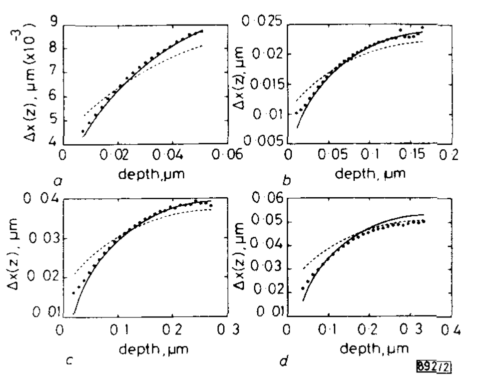

Fig. 2 *Predicted lateral spread profiles for As into a-Si using mixed moments*

a–d same as in Fig. 1
• TRIM-85 (SCOEF88) Monte-Carlo data
——— Kent formulas using eqns. 11 and 12
- - - - Formulas from Lorenz *et al.*[7]

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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D. G. ASHWORTH
R. OVEN
M. D. J. BOWYER

Solid State Electronics Group
Electronic Engineering Laboratories
University of Kent
Canterbury, Kent CT2 7NT, United Kingdom

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SELFPULSATION 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 investigation as a function of the gain section current. For selfpulsation 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 selfpulsation in semiconductor laser diodes has been demonstrated by the use of a selfpulsating multi-electrode laser diode[1] for optical timing recovery. The conditions for selfpulsation in a twin section device have been investigated[2,3] and it has been shown that reverse bias can promote selfpulsation by reducing the effective carrier lifetime in the absorber.

The electrical characteristics of the absorber have also been investigated by Harder *et al.*[4] 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 selfpulsation at the relaxation oscillation frequency. The effective load resistance for the absorber was shown to be important if selfpulsation were to be observed. This load resistance is dependent on the parasitic resistance between the sections.

In this Letter a selfpulsation 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 selfpulsating 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.*[4] This decrease in the absorber current at threshold is shown to be consistent with an 'S shape' V–I characteristic. It is also shown that within the selfpulsating regime it is not necessary to bias the absorber in a region of negative resistance to observe selfpulsation.

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 1·5 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 toal 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 30 Ω 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 1·76 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.[4] 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.[5] However by placing a 178 Ω 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 has been reproduced in Fig. 2. It shows the V–I characteristic under voltage control and under pseudo current control.

Harder *et al.*[4] have proposed that for gain section currents with an N-shaped V–I characteristic, selfpulsation may be

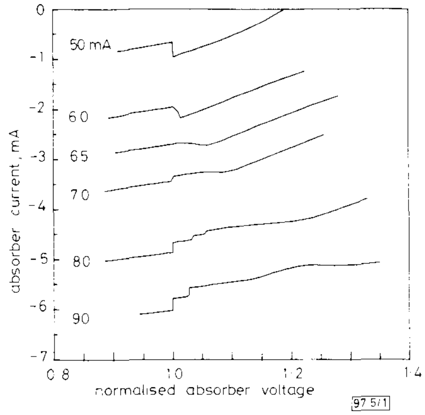

Fig. 1 *Normalised absorber voltage against absorber current for gain section currents between 50 and 90 mA*

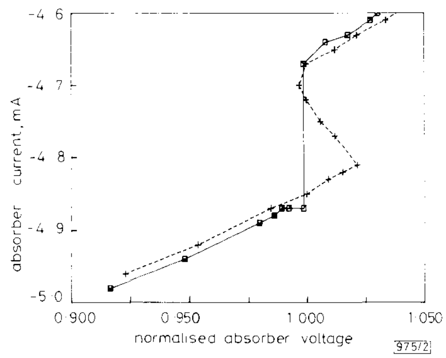

Fig. 2 *Normalised absorber voltage against absorber current at gain section current of 80 mA*

——— measured under voltage control
– – – – measured under pseudo current control

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 selfpulsation was observed at any operating point. Selfpulsation was only observed for V–I characteristics which contained an S shape. The oscillogram in Fig. 3 shows the selfpulsation in time for a gain section current of 80 mA.

It was also demonstrated that to observe selfpulsation it was not necessary to bias the absorber at an operating point

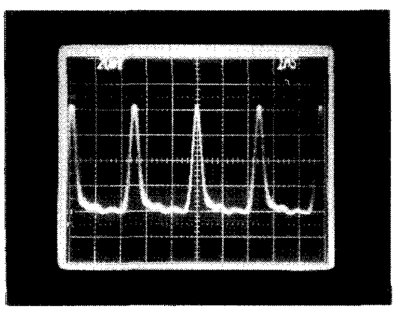

Fig. 3 *Selfpulsation waveform for gain section current of 80 mA*

within the S-shaped negative resistance. Above threshold over a range of absorber voltages the selfpulsation is maintained even when the absorber is operating at a point which has a positive differential resistance. Thus unlike Reference 4, negative resistance can be interpreted only as an indication of the existence of a larger region of selfpulsation within the absorber V–I characteristic. The absorber voltage range over which selfpulsation occurs increases with the gain section current. This absorber voltage range and the gain section current determine the limits of a complete selfpulsation operating regime. This regime is shown in Fig. 4 as a crosshatched area overlaid on the normalised absorber V–I characteristics for gain section currents between 65 mA and 90 mA.

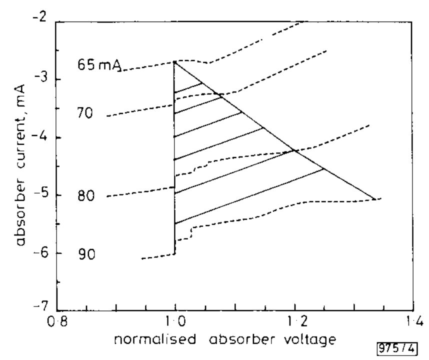

Fig. 4 *Selfpulsation operating regime overlaid on normalised absorber V–I characteristics for gain section currents above 65 mA*

Selfpulsation operating regime shown as crosshatched area

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.

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G. FARRELL
P. PHELAN
J. HEGARTY

Optronics Ireland Research Laboratories
Trinity College
Dublin 2, Ireland

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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),[1,2] no results on this topic have been reported until now. Based on improved modulation doped Si/SiGe heterostructures now available,[3] 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 precleaned and thermally prepared in the MBE system, a 40 nm undoped Si buffer was first deposited at 550°C. A 300 nm $Si_{0.68}Ge_{0.32}$ relaxed buffer was grown at 450°C. The structure then follows the layer sequence, as shown in Fig. 1*a*, 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.

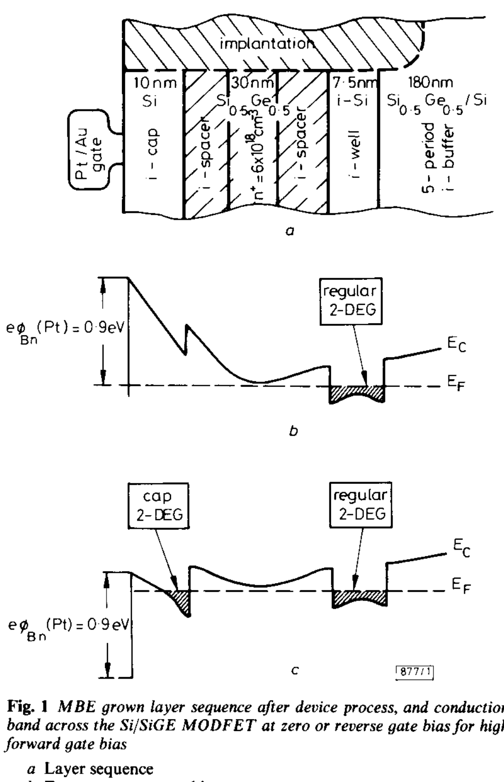

Fig. 1 *MBE grown layer sequence after device process, and conduction band across the Si/SiGe MODFET at zero or reverse gate bias for high forward gate bias*

a Layer sequence
b Zero or reverse gate bias
c Forward gate bias