Optical Engineering

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Abstract. A compact, low-cost semiconductor laser diode producing 40 ps full width at half maximum (FWHM) single-spike lasing pulses with 6 Watts peak power from a 20 μm stripe width is realized in the form of a simple single-heterostructure, grown by metal-organic chemical vapor deposition. The structure possesses a linearly graded doping profile extending from the p^+ and n^+ sides towards the *p-n* junction. This laser diode is operated under room temperature conditions and applies pumping current pulses (roughly 10 to 20 A/2 to 3 ns FWHM) achievable with a commercially available silicon avalanche transistor as an electrical switch. [DOI: 10.1117/1.OE.51.5.050503]

Subject terms: semiconductor laser; high-power picosecond pulse; single-heterostructure; gradient doping profile; room temperature; reproducible.

Paper 120242L received Feb. 24, 2012; revised manuscript received Apr. 13, 2012; accepted for publication Apr. 13, 2012; published online May 10, 2012.

1 Introduction

Applications such as high-precision laser radar,[1,2] 3-D time-imaging methods, spectroscopy, and lifetime studies call for small-size, low-cost, reliable sources which provide single-spike, high-power (1 to 100 W), picosecond-range (30 to 100 ps) optical pulses.

Since commercially available laser diodes generating isolated single optical pulses are usually limited to peak power levels in the sub-Watt range,[3] special techniques known as *q*-switching[4] and gain switching[5–7] are used to overcome the power limitation. The method described in Ref. 4, for instance, depends on a certain activation temperature, Ref. 5 applies spectral filtering to the gain-switched pulses, Ref. 6 uses ultra-short current pulses only achievable by means of a commercially unavailable GaAs transistor as the electrical switch, and Ref. 7 describes a specific laser diode structure with a very large equivalent spot size realized by asymmetry.

Here we discuss another simple laser diode structure that is operated under room temperature conditions and successfully demonstrates high-power, picosecond-range single-spike lasing in response to nanosecond pumping current pulses. These uncomplicated pulsing requirements can be realized by means of a silicon avalanche transistor as the switch. In our experimental investigations[8] the distinctive structure parameters which led to picosecond behavior were linear doping gradients of about 1.1×10^{22} cm^{-4} within ~3.5 μm starting from the p^+ and n^+ sides and extending towards the composite junction.

2 Laser Diode Structure

The AlGaAs/GaAs single-heterostructure (SH) laser diode structure (Fig. 1) was grown by metal-organic chemical vapor deposition (MOCVD) on an n^+ GaAs substrate. Subsequent processing makes use of a mask to form the mesa that is dimensioned for a current stripe width of 20 μm. The samples are cleaved to have a cavity length of 420 μm. The rear and front crystal facets serve as laser mirrors, each with a reflectivity of ~0.3, which is typical according to values quoted in the literature for uncoated gallium arsenide.

One important feature of the structure is the linear reduction in doping concentration towards the *p-n* junction, starting from the n^+ and p^+ sides, in which the doping value changes from 4×10^{18} to 8×10^{16} cm^{-3} within 3.5 μm and the *n* and *p* dopants overlap for about 0.5 μm around the composite junction. The heavily doped P^+ AlGaAs barrier has a concentration higher than 4×10^{18} cm^{-3}, the aluminium content of this hetero-injector being 30%.

To operate these MOCVD SH laser diodes, a compact pulser circuit is configured to achieve pumping current pulses with amplitudes in the range of 10 to 35 A, having a 2 to 3 ns full width at half maximum (FWHM), using a commercial Si transistor operating in the high-current avalanche mode.[9]

3 Measurement Results/Laser Characterization

Time-resolved spectra for the optical response to nanosecond-range pumping current pulses of different amplitudes (~11 to 27 A) were measured with a spectrograph equipped with a streak camera. Optical time-intensity profiles were extracted and recalculated to peak power values. The current pulses were deduced from the voltage drop measured across the load resistor with a 30 GHz oscilloscope (LECROY WM 830Zi-A). The measured laser pulses with their corresponding current pulses are plotted against time in Fig. 2(a).* The figure inlay [Fig. 2(b)] represents the time-resolved spectrum of the gradient doping profile SH laser diode for a single spike emission, here at a current pulse amplitude of 15 A. In the case of lasing without an emission tail, the maximum achieved peak power is 6 W, as calculated from the average optical power (322.6 nW) measured with an optical power meter (ANDO AQ-1135E with AQ-1972 sensor) at a 1000 Hz pulse repetition rate. The jitter-corrected FWHM of this optical pulse is 40 ps. A 9 A threshold current was determined in measurements using long current pulses (30 ns) and a pulse repetition rate of 1000 Hz.

Time-resolved spectra of the optical response corresponding to current pulses of Fig. 2(a), starting at the optical pulse labelled FWHM = 129.9 ps, are shown in Fig. 3. The high amplitude current pulses add a weakly pronounced

*The laser pulses in Figs. 2(a), 2(b) and 3 are not jitter-corrected, and therefore the FWHM displayed is broader than in reality and the extracted peak power has lower values.

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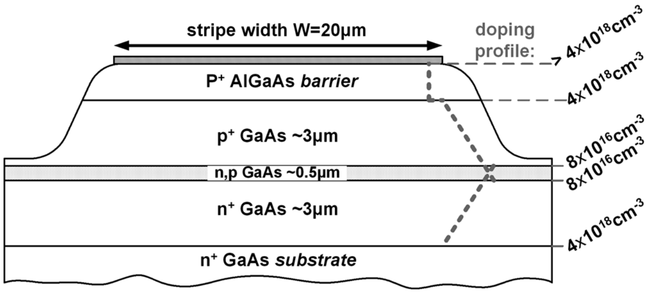

Fig. 1 Schematic representation of the SH laser diode (grown by the MOCVD method and cleaved to a length of 420 μm), including the doping profile with its concentration values.

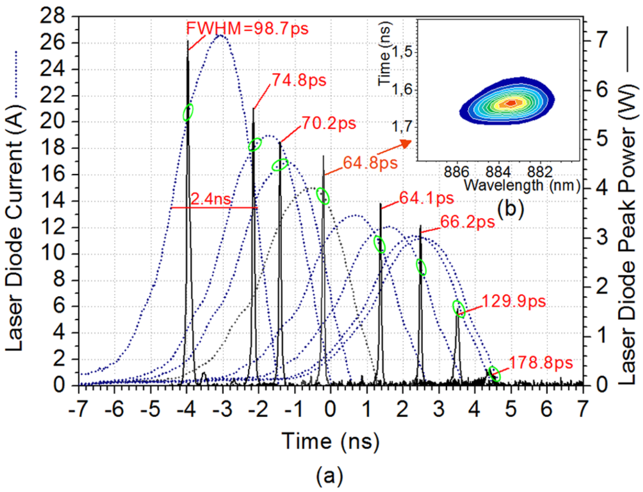

Fig. 2 (a) Pumping current pulses (dotted lines) and corresponding time-resolved laser pulse waveforms* (solid lines) measured with a streak camera having a two picosecond temporal resolution. Inlay: (b) time-resolved spectrum of the optical response to a current pulse of 15 A amplitude (ten intensity levels on a linear scale).

afterpulsing to the first spike emission. The spectra broadening may be related to an emission spread normal to the junction layer, within the active area. Time-integrated near-field profiles are presented in Fig. 4, where 'profile 3' illustrates

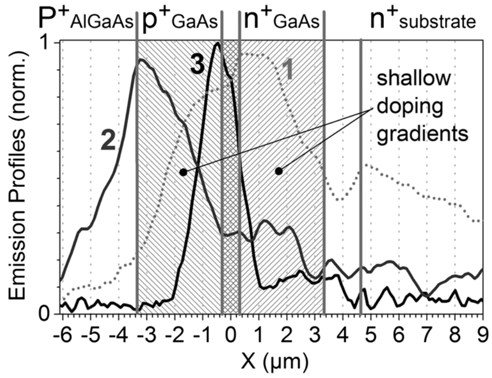

Fig. 4 Time-integrated near-field profiles showing the distribution of light intensity over a linear distance at the diode facet perpendicular to the *p-n* junction. Profile 1 marks the position of the *p-n* junction (low-current spontaneous emission), profile 2 shows the position of the AlGaAs/GaAs interface (carrier accumulation near the potential barrier, seen through a high-photon-energy filter), and profile 3 marks the lasing position.

the spatial lasing position. A typical current–voltage (*I–V*) characteristic for this gradient profile SH laser diode structure exhibits a relatively high breakdown voltage (≥5 V), measured with a semiconductor curve tracer in all diodes of this type.

4 Conclusions

We have shown that it is possible to achieve single lasing pulses of 6 W peak power and 40 ps FWHM without an emission tail by means of a simple MOCVD-grown SH laser diode structure, featuring shallow n^+ and p^+ doping gradients. The diode is operated at room temperature and exhibits uncomplicated pumping requirements, namely nanosecond-range current pulses.

The laser structure used here belongs to the category of single heterostructure lasers, which have been shown to yield short, high-energy optical pulses.[10] One likely additional reason for the good pulse quality observed in the present work is the following. The waveguide layer structure (which included a thick p-GaAs layer[10]) in this laser is composed

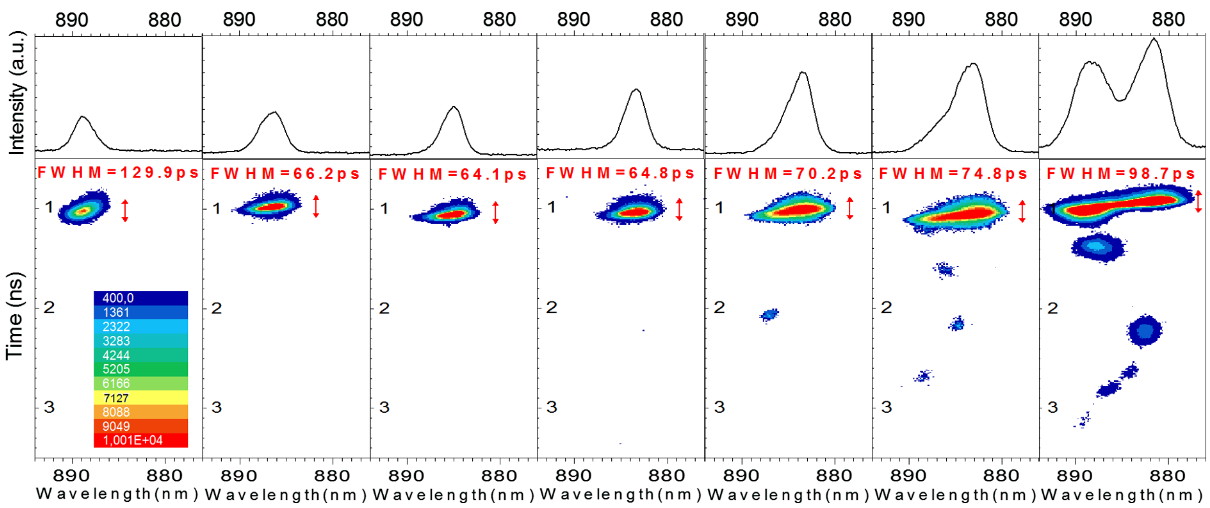

Fig. 3 Time-resolved spectra of the optical response equivalent to the optical pulses of Fig. 2(a) (starting at the 129.9 ps signal), displayed at ten intensity levels on a logarithmic scale.

of a material identical in composition to the active layer material. This means that its effective bandgap is very close to that of the active layer. For this reason, a certain amount of saturable absorption is present in the *p*-GaAs layer of the laser structure, which is known to sharpen gain-switched laser pulses.[11]

Acknowledgments

The authors thank Marina Kulagina, Boris Ryvkin, the CMNT at Oulu University, the Academy of Finland and Infotech Oulu GS for their support.

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