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100 W 50 ps gain-switched pulses from vertical-stack laser diode

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Abstract:
The advantages of a vertical stack configuration of laser diodes for high peak power, short-pulse generation under fast electrical pumping are demonstrated. 50 ps, 5 nJ optical pulses from a stack of 10 laser diodes have been obtained. This is the best time performance obtained to date from a multi-element gain-switched laser diode

Introduction:

The increase of active volume of laser diodes with conservation of current injection efficiency is one of the actual directions in high energy, high power pulse generation directly from semiconductor lasers. This method can provide much better performances in terms of electro-optic conversion efficiency and compactness than conventional diode pumped laser systems that can be of great importance for spatial and on-board applications. A simple solution has been proposed to generate sub-nanosecond optical pulses by short electrical pumping of laser diode matrix [1]. A demonstration of 1 μJ 300 ps pulses has revealed a surprising phenomenon that limits the further shortening of the pulses: the skin effect which disturbs homogeneity of current injection of each laser element in the array. To avoid this phenomenon, it is possible to reduce the transversal size of lasers in the direction perpendicular to the current flow. The present work is an experimental demonstration of this solution: fabrication, and detailed investigation of pulsed emission in vertical stacks of laser diodes.

Experimental setup:

In order to perform an accurate comparison between horizontal and vertical active volume expansion, the arrays and stacks were fabricated from the same AlGaAs single quantum well DH structure. Each laser element has a 100μm-stripe width and 600μm length. The distance between elements in the horizontal array is 400 μm. In vertical stacks, this intra-element distance was imposed by a wafer thickness of about 120μm. A schematic view of conventional horizontal arrays and vertical stacks used in our study are presented on Fig 1. To provide high-speed current pumping, the samples were mounted on a special holder integrating two coaxial lines of 50 Ohms. An electrical pulse generator, based on shock-wave avalanche diodes, was specifically developed for this

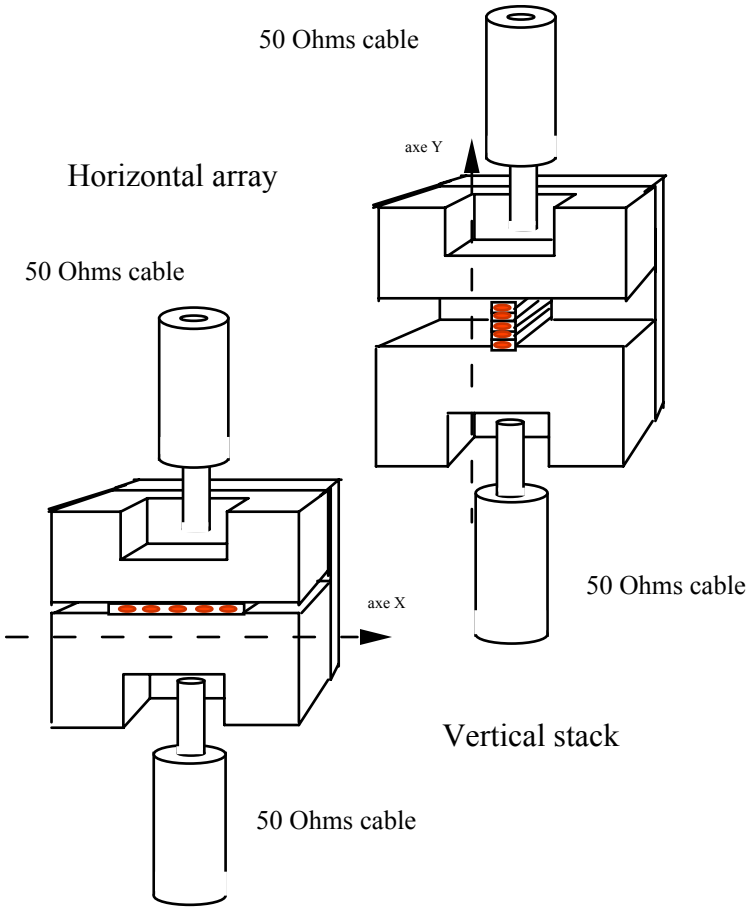

Figure 1. General views of vertical stacks and horizontal array mounting.

application. It could provide 2 different kinds of electrical pulses in the 50 Ohms coaxial line: 120ps 800V Gaussian pulses and 400 ps 2kV triangular pulses. The peak current amplitude at threshold condition for the horizontal array was 15 A and for the vertical stack was 1.5 A under 400ps pumping. For 120ps pulses the required current amplitude was considerably increased up to 7-8 A. This increase is due to the fact that the 120ps pump time is considerably shorter than the 1- 2 ns relaxation time of the laser active medium. The emission of lasers was imaged on the 7 mm wide input slit of a streak-camera by a simple doublet lens with f=100mm and NA~0.1. The time-resolved images of near-field distribution were measured by a H1587 streak-camera with 2 ps resolution (high-speed unit). The peak energy of the optical pulses was estimated from measurements of the average power and measurements of temporal profiles.

Description of results:

Fig. 2 represents the typical croissant-like temporal distribution of gain-switched pulses emitted from a laser diode array under 400 ps pulse pumping. The dispersion of the

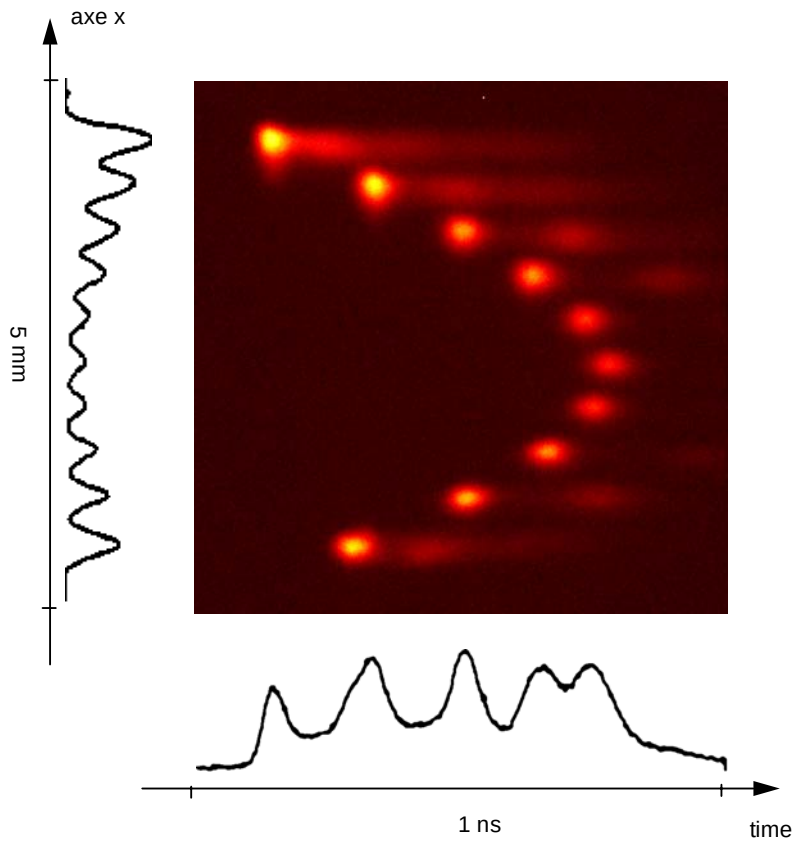

Figure 2. Croissant-like delay behavior of starting time in horizontal array under 400ps pumping.

starting time of the pulses reaches a value of several hundreds of picoseconds that is one order of magnitude larger than the duration of each single pulse (50-70ps). The origin of this phenomenon is a skin effect in the laser wafer. The current flowing through terminal elements of the array has a weaker magnetic coupling to the total current compared to the current flowing through central elements. Therefore, the resulting inductance of terminal elements is smaller and fast pumping is more effective. The similar effects were observed tens years ago in Gunn diodes [3]. As a matter of fact, an estimation of the skin depth is possible through the following expression : $\delta = c/(2\pi\ (\sigma\ \mu\ f)^{1/2})$, where c is the speed of light, σ the electrical conductivity of 10^3ohm cm for a GaAs-n wafer, μ the magnetic permeability, f the current frequency taken at 1 GHz for 400 ps pulses. This expression gives a skin depth of 1 mm, which is comparable to the width of the laser array and considerably decreases the pumping level in the central part of the laser array. To avoid this phenomenon, two solutions can be proposed: a spatial and temporal correction of the injection current [3] by a specific design of the bonding or the vertical piling of active mediums in a vertical stack. The first solution has better heat-transfer properties that are a

serious advantage for high repetition rate systems. The second solution is more adapted for low-rate high pulse energy emission due to multiple reasons: smaller contribution of the skin effect and best impedance matching with the 50 Ohms electrical pulse line. This permits to have the best electro-photonic conversion efficiency for short electrical pumping. This simple idea was proposed in [2]. Fig 3 demonstrates the emission of this 10 elements vertical stack under 120 ps pulse pumping. For current amplitude ten times
Figure 3 Emission of vertical stack under 120ps pulse pumping.

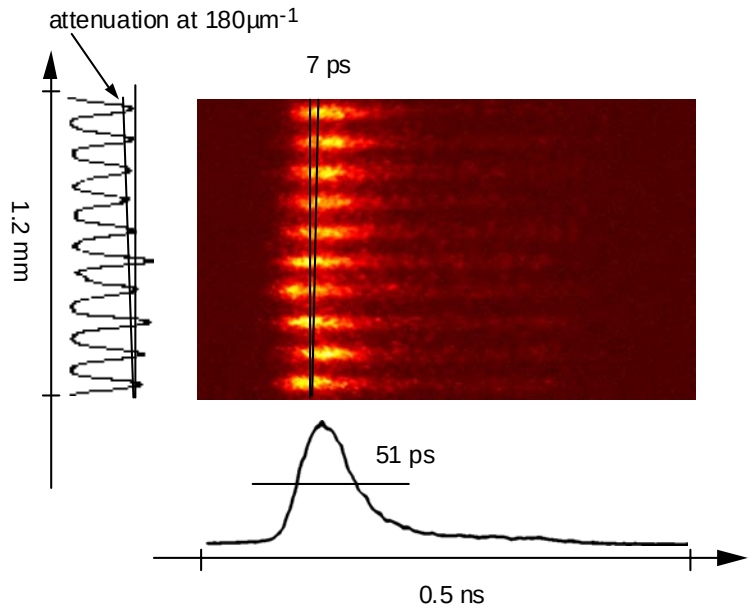

Figure 3 Emission of vertical stack under 120ps pulse pumping.

smaller than for the 10 elements horizontal array, gain switched pulses of 5nJ with a total duration of about 50 ps were obtained. The streak camera image of the laser emission reveals a small inclination of the vertically distributed spots that correspond to the current propagation speed in the stack. An accurate measure gives a value of about 8ps per mm that correspond to an effective propagation factor of about 1.5-2. Furthermore, a precise measurement of the amplitude distribution of the optical pulses in the vertical stack indicates a weak decrease of the amplitude in the direction of the pump pulse propagation. This attenuation was estimated at 180 µm-1. Indeed, the electrical pumping signal should be attenuated in distributed systems like vertical stacks, due to the finite resistance of laser contact regions and the voltage jump on the p-n junction This two kind of attenuation can be approximately expressed as: $\alpha_{resistance}$ = 1/2*R/Zo, α_{jump} =1/2*ln(1-Uo/(Ip*Zo)), where R is the longitudinal resistance per unit length of the transmission

line formed by the vertical stack of lasers, Zo is the characteristic line impedance, Uo is the total voltage jump on the stack, Ip is the pumping current. The estimated total value of these losses is about 120μm-1. The higher experimental value can be explained by a perturbation of Zo in the region of the laser structure.

Discussion:

These observations show the main limits related to a vertical increase of volume. To have a spatial homogeneity of the emission starting time smaller than half of pulse duration, the vertical size of the laser stack cannot be higher than several tens of elements. To compensate the contribution of the voltage jump and contact resistance in the attenuation of the pump signal, a pyramidal vertical structure with variable width of elements or laser systems with variable impedance can be considered, but it seems more complex than the specific bonding of horizontal arrays. In any way, only a solution with vertical piling of p-n junction laser diodes can provide an efficient matching with conventional 50Ohms electrical lines at high speed pumping. In the present work a 3% electro-optic conversion efficiency has been obtained that is two orders of magnitude better than for horizontal arrays.

This higher coupling efficiency has permitted us to use the pump generators with smaller voltage amplitude but with shortest pulse duration. The pumping of the laser diode with pulses comparable to the build–up time of gain switch leads to higher injection levels, to higher Δg and to shorter pulses. In the present experiment, a 2-3 times higher peak energy and a decrease of the pulse duration from 60 ps to 40-45 ps has been obtained by reducing the pump pulse duration from 400ps to 120ps.

The technique for realizing laser diode stacks is at present essentially manual, which considerably limits large-scale low-cost production but multiple ways of development can be envisaged, such as multi p-n junction laser structure, post epitaxial serial connection by specific contact topology, multi-photon laser structures. It seems that the development of such devices can be an important way to obtain efficient compact and robust picosecond sources.

Conclusions:

We have studied vertical stacks of laser diodes for short pulse generation under fast electrical pumping. 50 ps 5 nJ optical pulses were obtained in such structures. These are the best pulses performances obtained from multi-element gain-switched laser. We have determined the limits of such a configuration in terms of the simultaneousness of starting

time and amplitude homogeneity. We consider that this structure has a potential in free-space communication and detection applications.

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