Generation of High-Power Picosecond Laser Pulses

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ABSTRACT

We present a method of highly dynamic carrier injection into the active zone of a Fabry-Perot laser structure, which enables us to modulate the optical refractive index of the optical waveguide. We will demonstrate experimentally, that the optical refractive index can be changed in such a way, that the laser diode emits light pulses with FWHM around five to ten times smaller and optical peak power up to two orders of magnitude larger than by using normal carrier injection. These extremely improved lasing characteristics using cheap and easy to manufacture devices are of great interest for sensor applications.

I. INTRODUCTION

The fast development of more complex laser diode structures has led to the possibility of generating sub-picosecond laser pulses, Delfyett et al [1], Nakazawa et al [2]. With high speed data transmission being the main application, these ultrashort laser pulses don't need to have high energy as long as they can be reliably received and detected. In this case the light is transmitted using an optical fiber with only small losses. However, for optical measurement applications the environment may cause significant losses which requires the use of as much power as possible.

Higher laser power means large active volume, therefore the concept of quantum-well structures cannot be used in the same way as in small volume lasers. In small quantum-well lasers, recombination energies are the well-defined discrete energy levels in the otherwise continuous energy bands of the semiconductor, leading to a narrow spectrum of the light, and single-mode operation is also possible. If the volume is very large, recombination between discrete energy levels can be neglected, and the heterojunctions serve only to confine the carriers inside the active volume. This, however, leads to higher threshold currents, but is easy to overcome by using short and strong current pulse injection. In the remainder of this introduction we describe the investigated laser structure as well as the method of excitation. Section II shows the laser pulses in the time domain, whereas Section III presents the results in the spectral domain, all of which are summarized and concluded in Section IV.

The structure of the used laser diodes is shown schematically in Fig. 1. It's a simple three layer Fabry-Perot structure that can be grown by using almost any technology. The active layer is confined by a heterojunction at the p-contact side and by a pn-junction at the ground contact side. This forms an asymmetric waveguide, and the light is able to penetrate relatively far into the substrate. Due to this fact and the large active volume, threshold carrier density is quite high. Because of the absence of a saturable absorber, we can only generate laser pulses by gain switching, that means we have to generate short current pulses first. This is done using a fast avalanche transistor as a switch, that connects a charged capacitor to the laser diode for a short time. We measure the current through a very small series resistor to the capacitor. FWHM of the current pulses is typically 3-5ns with a rise time of around 2ns. The maximum amplitude depends on the capacitance and is typically 20-25A. Since the voltage at the capacitor can be set using an external DC power supply, the peak amplitude of the current can be changed in a certain range. The base of the avalanche transistor is triggered by a rectangular 20ns voltage pulse having a PRF of up to 1MHz.

II. TIME EVOLUTION OF THE LASER PULSES

The laser light is coupled into an optical fiber and directed onto a fast 60GHz photodetector. The output signal is measured using a 50GHz sampling oscilloscope. In order to rescale the recorded signal from volt to watt, the average optical power is measured and compared to the value found by integrating the photodiode output numerically. The laser diode is temperature controlled, in this paper we use T=23°C and PRF=4kHz for all measurements, if not mentioned otherwise.

For a DC voltage of V_{CC}=240V the avalanche transistor works in an amplifying mode rather than in avalanche mode. The current pulses have lower amplitude and larger FWHM than for V_{CC}>240V. Fig. 2 shows the corresponding laser pulse. The peak power is in good agreement with data from the manufacturer, Laser Diode, Inc., New Jersey, USA, obtained by using 200ns excitation. We can see an overshoot at the beginning, that is about 150% of the amplitude in the middle of the pulse. The overshoot is caused by the fact that the temporal change of the photon density is proportional to the actual photon density, which means the higher it is the faster it will grow. Since there is no photon density before the exceeding of threshold, the photon density rises slowly after reaching threshold, causing a delay. Then the buildup of photon density gets faster and faster and therefore overshoots the steady state value. The important thing is, that after a steady state has been reached, there will be no more spiking effects if the injection level is still changing.

We can enhance the overshooting by using faster and stronger current injection, in our case by increasing V_{CC}. Fig. 3 shows a laser pulse for V_{CC}=250V. The time shift of the whole pulse in comparison to Fig. 2 is due to a shift of the trigger pulse for the oscilloscope and therefore is not related to the variation of the injection current. The first spike is now one order of magnitude larger than the steady state value, rise time and FWHM have decreased. The fast and strong injection of carriers create a greater non-equilibrium which causes the photon density to overshoot significantly. By continuing to increase V_{CC}, we observe a very important effect, Volpe [3], Kompa et al [9], as can be seen in Fig. 4. A second spike starts to evolve about 1.5ns after the first one. This becomes more evident in Fig. 5, which also shows that the amplitude of the first spike is decreasing. As stated above, an overshoot is not likely to evolve after steady state has been reached, therefore the photon density of the second spike must occur at wavelengths different from the first spike, where no photons were present before. Due to the additional delay of 1.5ns, even more carriers can be injected into the active zone before they recombine heavily, creating the second overshoot. The decline of the first spike can therefore be connected to the large amount of carriers. Since the optical refractive index is a function of frequency and carrier concentration, Bennet et al [4], Weber [5], the index profile of the waveguide is affected in a way, that enables waveguiding at other wavelengths, whereas waveguiding at typical wavelengths of around 904nm for GaAs is handicapped. For large V_{CC} we can see in Fig. 6, that the second spike has much enhanced overshoot potential compared to the first one, which is no longer existent at extremely high injection levels. Using a larger capacitor, we were able to yield an optical peak power of nearly 440W from a device that was rated to have 5W, as shown in Fig. 7.

III. SPECTRA OF THE LASER PULSES

The laser light is coupled into an optical fiber that is connected with an optical spectrum analyzer. We will show the spectra under the same measurement conditions as in section II in order to be able to compare the results. For normal carrier injection, we measure quite the same spectrum as given by the manufacturer, see Fig. 8. For higher injection levels, when the second spike starts to evolve, Figs. 9 and 10, we can see that recombination also occurs at smaller wavelengths. The optical refractive index has changed allowing the laser condition to be fulfilled also at higher energies. The reduction of the first spike in the time domain cannot be seen here, because the spectrum is integrated over time. When steady state has been reached after the second spike, carrier density has decreased due to the heavy recombination thus shifting the spectrum from smaller wavelengths back to 904nm. Therefore we will always observe two peaks in the spectrum, unless the excitation current pulse is so short that the laser condition is no longer fulfilled after the second overshoot. The spectrum for extremely high injection level is shown in Fig. 11. The peak at normal wavelengths has been shifted from 904nm to 907nm due to the bandgap shrinkage caused by increased carrier density. The optimum case of waveguiding modulation would be, if the spectral part at smaller wavelengths has more peak power than the part at typical wavelengths, like in Fig. 12.

Since the maximum of the material gain moves to higher energies with increasing carrier concentrations, we can explain why the spike at smaller wavelengths is much higher in amplitude than the one at normal wavelengths.

IV. CONCLUSION

We have seen that is is possible to modulate the optical refractive index using strong and highly dynamic carrier injection. Using SH laser structures, waveguiding is affected allowing lasing at frequencies that have maximum material gain and therefore extremely high optical power is reached. Preliminary simulation and physical explanations, Gel'mont et al [6], Sola [7], agree well with the oberved results and more precise modeling is being done to optimize these results. This will be published in the near future. The generation of high power laser pulses using semiconductor laser diodes enables the substitution of large gas or solid-state lasers, so that measurement devices can be shrunk in size, which is important for all applications in mechatronics. It is even more promising if unexpensive standard devices can be used. Employing these powerful picosecond laser pulses, we realized a pulsed laser radar system, Biernat et al [8], with outstanding advantages: simple and cost effective setup, high resolution both lateral and radial, totally eye-safe laser emission and the ability to detect also dark objects.

ACKNOWLEDGEMENT

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FIGURES

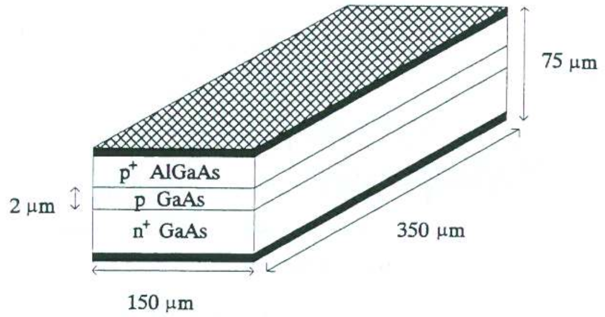

Fig. 1 Structure of the investigated laser diodes.

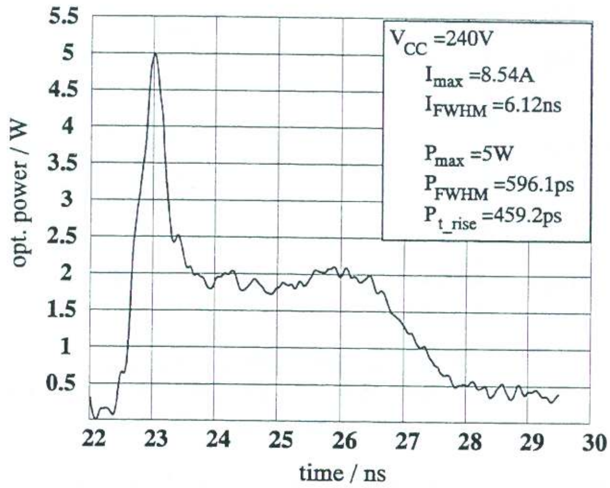

Fig. 2 Laser pulse at slightly above threshold injection (transistor in amplifying mode).

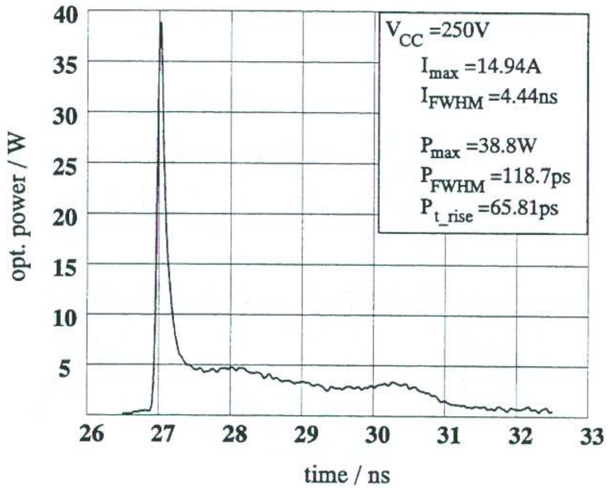

Fig. 3 Laser pulse at moderate injection level. (transistor in avalanche mode).

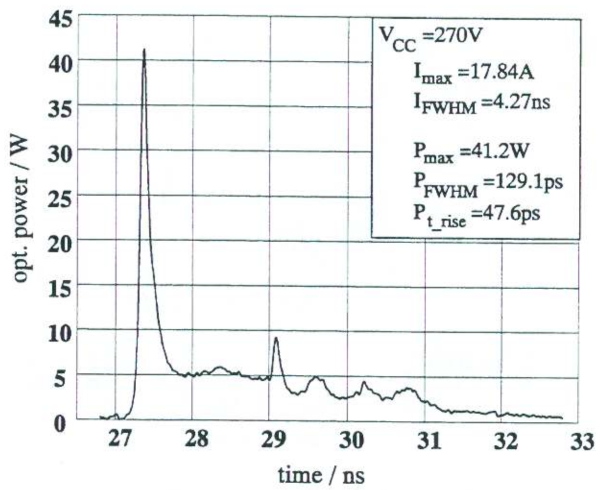

Fig. 4 Laser pulse at high injection level. Evolution of second overshoot at t=29.1ns.

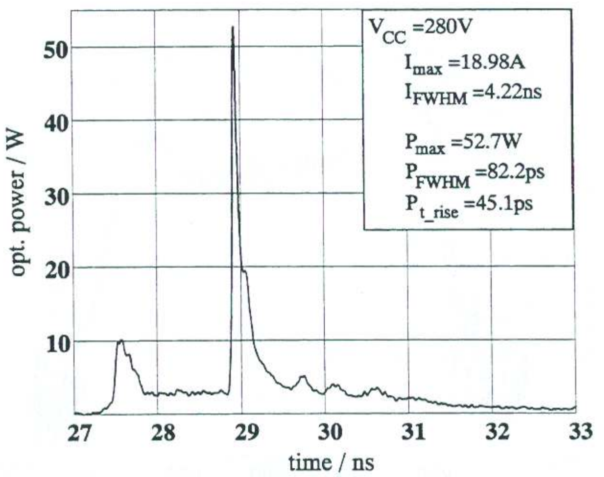

Fig. 5 Laser pulse at high injection level. Further evolution of the second spike and reduction of the first one.

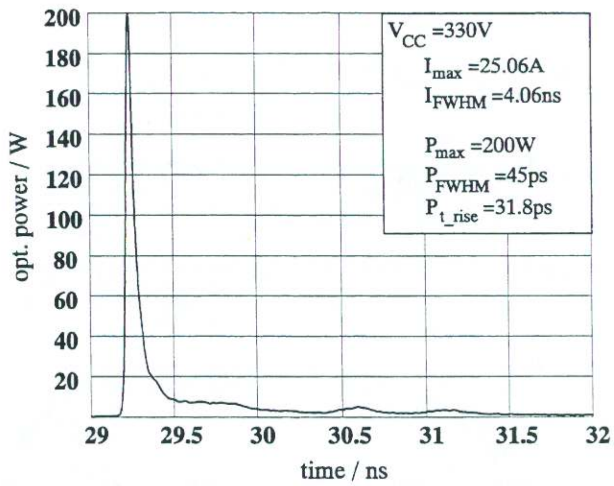

Fig. 6 Laser pulse at extremely high injection level. Fully developed second spike, first overshoot is no longer existent.

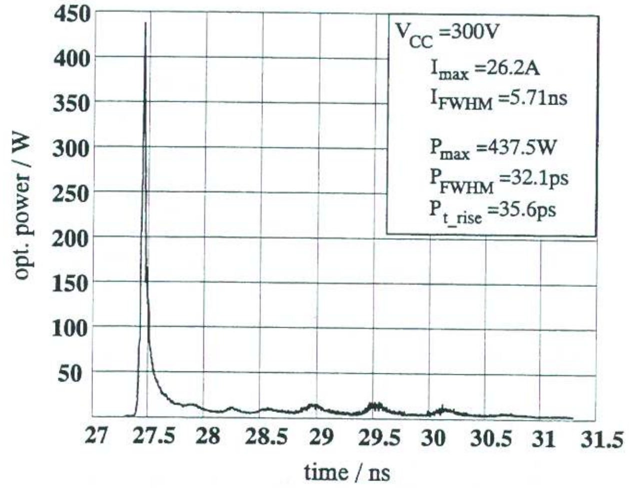

Fig. 7 Laser pulse with highest obtained optical power (T=16°C, PRF=2kHz).

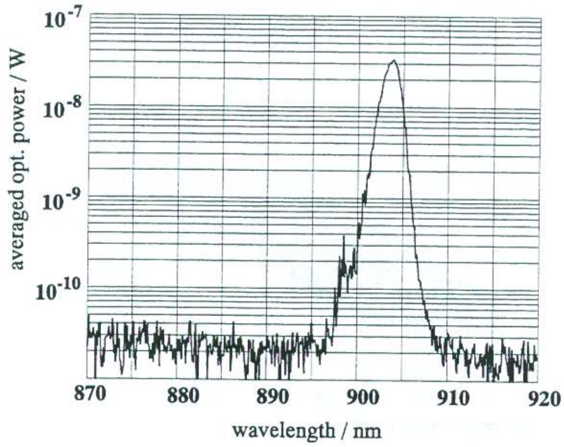

Fig. 8 Spectrum of the laser pulse shown in Fig. 2.

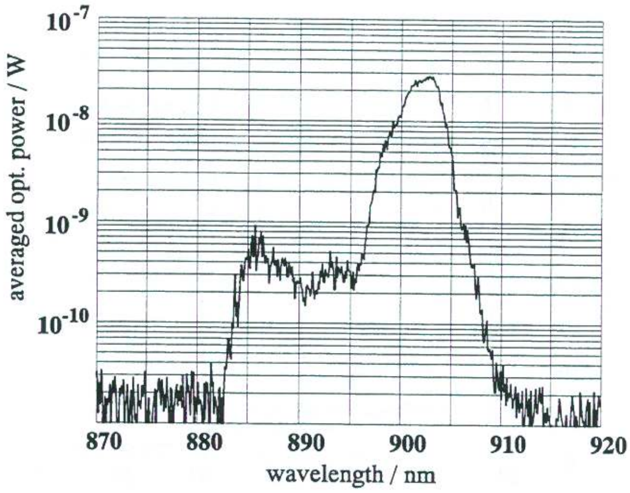

Fig. 9 Spectrum of the laser pulse shown in Fig. 4. Evolution of the second overshoot at smaller λ.

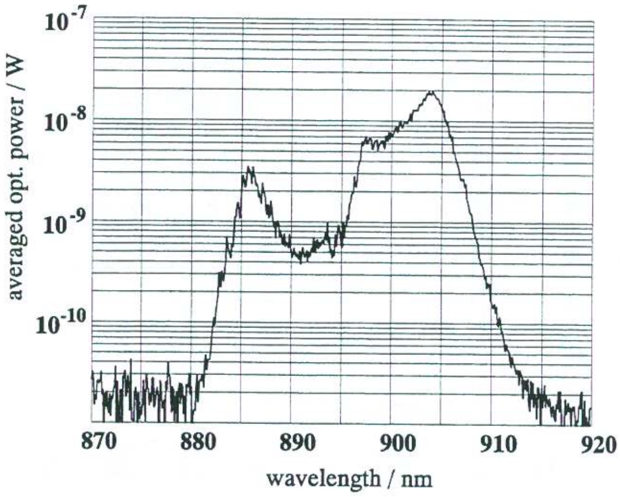

Fig. 10 Spectrum of the laser pulse shown in Fig. 5. Further evolution of the second spike.

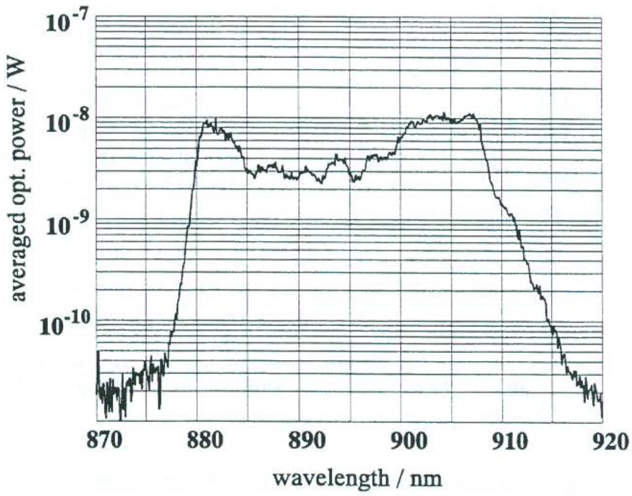

Fig. 11 Spectrum of the laser pulse shown in Fig. 6.

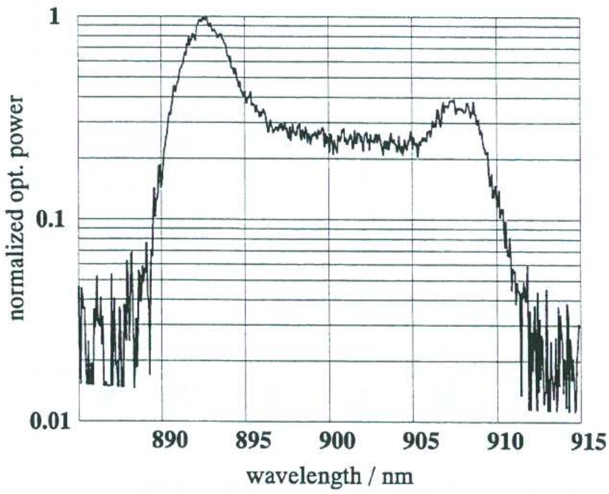

Fig. 12 Enhanced spectral distribution.