loops which, when properly adjusted, allows stable mode-locking and pulse generation with minimal jitter.⁴ If the optical cavity is left fixed and the optoelectronic delay is adjusted, the laser moves to another stable mode to restore the resonant condition and preserve the pulse width. Thus we could access the multistable modes of the external cavity system by adjusting the optoelectronic delay or loop filter frequency.

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1815

High power low confinement AlGaAs/GaAs single quantum well laser diode operating in the fundamental lateral mode

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It was recently proposed,^{1,2} that the power density related to the window width (in $W/\mu\text{m}$) of a laser diode can be substantially improved using a low confinement epitaxial structure. Keeping a reasonable high value of the intrinsic gain in the active region, a low confinement structure shall work also with a low modal gain value. The power optimization process is essentially connected to the attenuation coefficient of the laser waveguide α . When operating with an α value around 1 cm^{-1} and pursuing a high differential efficiency, the modal gain should have a value around 5 cm^{-1} and the laser length should be increased accordingly.² A beneficial consequence of the low modal gain value is the possibility to increase the stripe width while preserving well the operation in the fundamental lateral mode above the threshold.

Epitaxial structures with a 6-nm Single Quantum Well (SQW) and 0.007 confinement factor were prepared by MBE. The waveguide width was approximately $1\text{ }\mu\text{m}$ and the active region was placed asymmetrically inside, close to the p type confinement layer. Ridge stripes were formed by anodic oxidation and etching down to $0.09\text{ }\mu\text{m}$ above the waveguide margin. The stripe width was $12\text{ }\mu\text{m}$. The final anodic oxide served also for the electric isolation. Devices 2 to 6 mm in length were cleaved and cut from the wafer. For test measurements the windows remained uncoated. The devices were mounted upside down on Cu submounts. All measurements were per-

formed using short, high current pulses (150 ns, 1 kHz).

The lowest measured threshold current density was 3 kA/cm^2 for a 3-mm-long device. This unexpected high value prevented the CW operation testing. It is probably due to the Be diffusion across the undoped waveguide, down to the n type confinement layer,³ which determines a low injection efficiency. From the reverse of the differential efficiency vs length curves, an attenuation coefficient equal to 1.5 cm^{-1} has resulted, close to the 1 cm^{-1} value used for designing the structure.² From a 2.5-mm-long device the operation in the fundamental lateral mode was observed up to 1.3 W (4.7 A over threshold). The width of the lateral far field pattern is 4° close to the threshold and increases up to 5° at higher currents.

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1700

Room B

Stimulated Scattering and Laser Spectroscopy

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CTuQ1

1700

Switching of Raman scattering

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In transient stimulated Raman scattering (SRS), efficient conversion of short pump pulses to Stokes radiation is difficult to obtain. A short seed pulse at the Stokes frequency increases the efficiency and may induce full depletion of the pump pulse, even when the pump power is too low to scatter efficiently without seed. However, for low pump powers the Raman polarizability induced by the pump and seed pulse decays, which results in a

CTuQ1 Fig. 1. Experimental pulse shapes; grey curve: CO_2 input pulse, thick solid curves: depleted CO_2 output pulse and Stokes output pulse, thin curve: Nd-YAG input pulse train. (a) Extended Stokes pulse, (b) terminated Stokes pulse, and (c) Stokes pulse terminated due to a phase change within the first seed pulse.

terminating Stokes pulse, even when the pump pulse itself is long. Nevertheless, the Stokes pulse can be wider than the dephasing time of the Raman polarizability or the width of the seed pulse by an order of magnitude. Applying a second seed may once again induce a sufficiently large Raman polarizability but only if the phase of the Stokes seed matches the phase difference between the pump and remaining Raman polarizability. If not, the polarizability induced by the first pulse and consequently the conversion efficiency for the Stokes radiation decreases. Therefore, it is possible to switch off the Stokes pulse by applying a second seed with appropriate phase and intensity.

We have examined the behavior of the generated Stokes pulse in both experiments and simulations when a second seed pulse interacted with the coupled pump and Stokes pulses in a Raman medium. In the experiments a Q-switched Nd-YAG and a TEA CO_2 laser were used. The seed wave at the Stokes shifted frequency of the CO_2 radiation was generated by Raman resonant four wave mixing (FWM).¹ Both the generation of the seed by FWM and the scattering of the CO_2 radiation by SRS occurred in the

CTuQ1 Fig. 2. Calculated pulse shapes: (a) single seed at $t = 100$ ns, (b) extended, and (c) terminated Stokes pulse by a second seed pulse at $t = 120$ ns.

same multi-pass Raman cell,^{1,2} filled with $p\text{-H}_2$ gas. A train of Nd-YAG pulses, generated in a ring delay line, produced a train of seed pulses by FWM. Due to small vibration and air current induced optical path length changes in the delay line, random phase differences occurred between pairs of neighboring seed pulses. Figure 1 shows the measured Nd-YAG input pulse train, the CO_2 input pulse, the depleted CO_2 output pulse, and the generated Stokes pulse. An extended Stokes pulse is generated where the newly induced Raman polarizability was in phase with the previously induced polarizability (a). The Stokes pulse is terminated (b and c) when the newly induced polarizability was out of phase with the previous one. Simulations of the pump and Stokes pulses were based on the coupled equations for the pump and Stokes wave amplitudes and the Raman polarizability for transient SRS.^{3,4} In Fig. 2 the calculations also show an extended Stokes pulse for a second seed with the same phase as the previous seed (b) and a terminated Stokes pulse (c) when the phase of the second seed was switched by 180 degrees. It is thus shown to be possible to use the Raman medium as a switch where a low power optical pulse at the Stokes frequency is able to switch on and off a high power Stokes wave.

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CTuQ2

1715

Laser pulse compressor utilizing stimulated Brillouin scattering and laser induced plasma switching

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One fundamental problem with current laser sources is that while the mechanisms that produce amplification by stimulated emission may be modified by a variety of means to produce laser pulses of different pulse lengths, this is of course specific to the laser in question, and in most cases there is an upper and lower limit that may be achieved. The upper limit to pulse length is for several laser sources continuous wave (CW) operation. The lower limit is often determined by the stability of the lasing state and several other factors, such as pumping scheme, Q-switching, etc. However, as is most often the case, if a specific pulse length is desired, a specific configuration of the laser system may be developed to meet that need. Then normally only the desired pulse length can be obtained. Nonlinear pulse shortening (NLPs) was discovered in the early 1970s and has been discussed by various workers.¹⁻³ This technique utilizes the property of stimulated Brillouin scattering (SBS) and/or stimulated Raman scattering (SRS) to shorten pulses. Pulse lengths in the 100-psec region at 2 mJ per pulse have been created utilizing SBS and 1 psec utilizing SRS, which produces a rather large wavelength shift. These processes have been shown to be successful for a variety of laser systems operating at a variety of wavelengths. In this paper we discuss a method specifically using a Nd:YAG laser which is operating at wavelengths in the vicinity of $1.06\text{ }\mu\text{m}$.

Pulse shortening is accomplished in two ways. First, to build up the hypersonic grating (HG) required to perform phase conjugation (PC), a threshold intensity level must be reached. Therefore, there is a finite buildup time. This tends to steepen the rise time of the reflected PC pulse.

Second, the action of the grating envelope shortens the pulse under certain conditions. This is shown schematically in Fig. 1. The beam, shown at the top of the figure, is focused into the SBS cell. The vertical dotted line indicates the position where the HG is initiated. Initially the HG is formed at that point and runs downstream from that point at the velocity of sound of the medium. The PC pulse is reflected from that point and is Doppler shifted off the moving HG and travels in the opposite direction as the HG at the speed of light in the medium. Concur-

CTuQ2 Fig. 1. Generation of a shortened pulse using a long focal length lens geometry.

CTuQ2 Fig. 2. Generation of a shortened pulse due to the combined action of SBS and plasma absorption.

rently, the HG begins to form upstream in the direction of the reflected pulse. This is the beginning of the HG, hence the PC mirror, and it forms upstream at close to the speed of light. This leading edge of the HG envelope may be thought of as a moving mirror traveling in the direction of the reflected pulse and in the opposite direction of the incoming pulse. This causes the energy to be redistributed into a compressed pulse as shown. The optimum pulse compression is achieved when the period times the velocity of light in the medium is equal to twice the effective interaction length, which is often quite long. The long interaction length is often accomplished by either a very long cell, a tapered waveguide, or by focusing through a long focal length lens.

The technique employed in this experiment does not utilize the above process. Rather, here the SBS cell is used primarily to produce a reflected phase conjugate of a portion of the incoming pulse. The pulse is then truncated by a mechanism that will be discussed below. This has the disadvantage that the reflection efficiency can never be very high. Reflection efficiencies of around 30% have been seen as opposed to over 70% that has been seen for long interaction length systems.

The above discussion relates directly to the sharpening of the rise time of the reflected pulse; however, it does not address the sharpening of the fall time of the pulse. This is accomplished by a laser induced plasma that, once developed, absorbs the incoming radiation. Here the action of the plasma is defined as a plasma switch.

Shown schematically in Fig. 2 is the action of SBS and the BPS on the incom-