In conclusion, we have demonstrated a new mechanism for the production of ultrafast electrical pulses. This approach, based on optical rectification, has the potential to generate pulses limited in duration only by the laser pulse width. In addition, the scheme may be used to inject electrical pulses at arbitrary points in a device or circuit.

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CTuP30

### Effect of noise on the power spectrum of passively modelocked lasers

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Modelocking is a common technique employed to produce ultrashort optical pulses from lasers over a wide range of wavelengths. Actively modelocked lasers, for example, are driven by a stable external frequency reference. In this case the timing fluctuations are related to the modulator signal and can be treated as stationary processes.[1,2] The theory revealed spectral characteristics that are commonly referred to as a spike and a pair of pedestals, with the spike resulting from a delta-function-like shape at each harmonic owing to the external locking source. One pedestal, or side band, at each harmonic is due to amplitude fluctuations and the second is due to timing-jitter fluctuations. The latter is harmonic-number dependent. For more than a decade, this theory was applied to the fundamentally different case of passively modelocked lasers, but the results were not adequately explained.

A passively modelocked laser is a free-running laser where the modulation is produced internally. Therefore timing fluctuation are commutative, and are described as a nonstationary processes.[3,4] Based on that description, we found that for timing-jitter fluctuations between successive neighboring pulses that are uncorrelated in time, Lorentzian shaped spectra at different harmonics with FWHM proportional to the square of the harmonic number will result. Correlation time between timing fluctuations of different pulses in the train tend to produce spectra at different harmonics that are both Gaussian in shape and have FWHMs that increase linearly with harmonic number (for harmonic number greater than a minimum value). As the ratio of the correlation time to repetition time increases compared with the ratio of the repetition time to rms timing-jitter between neighboring pulses, more harmonics will have the Gaussian shape and linear dependence of the FWHM on frequency.

Amplitude fluctuations were found to have only a small effect on the power spectrum.
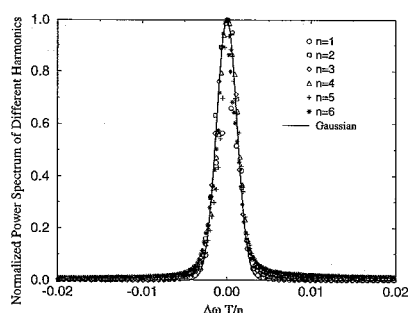
CTuP30   Fig. 1   Normalized intensity spectra of the first six harmonic number versus the deviation frequency divided by the harmonic number *n*. The solid curve describes a Gaussian.

Small amplitude fluctuations or strong fluctuations with long or short amplitude correlation times both have little effect on the shape of the spectra. Other cases of strong amplitude fluctuations mainly extend the wings of the spectra around different harmonic number.

Experimental results for an external cavity passively modelocked semiconductor laser are presented in Fig. 1. The first six measured harmonics of the normalized power spectra had Gaussian shapes with the FWHM linearly dependent on harmonic number. This indicate long relaxation time ($>$1180 T, where 1/T = 608.5 MHz is the repetition frequency) for the timing-jitter fluctuations. The rms timing-jitter fluctuations was calculated by fitting the FWHM to that of the Gaussian, yielding rms around 2×10^{-4} T.

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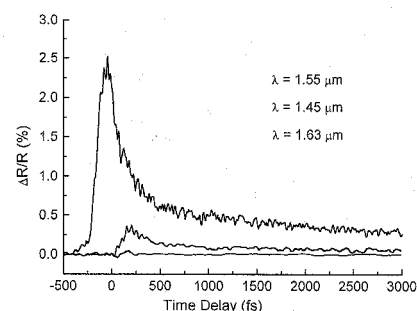## CTuP31

Saturation characteristics of a 1.55 µm GaSb/AlSb MQW Fabry–Perot mirror

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The need for convenient passive modelocking elements in solid-state and fiber lasers has led to the development of saturable absorbers based on quantum well structures incorporated into Fabry–Perot mirrors.[1] Considerable success has been reported for GaAs/AlGaAs systems for use near 800 nm. Here we report measurements of the saturation and recovery characteristics of a GaSb/AlSb system that has favorable characteristics for modelocking lasers operating near 1.55 µm.

Our sample consisted of 5 layers of an $Al_{0.37}Ga_{0.63}Sb$/AlSb as a quarter wave stack grown on a GaSb substrate; this structure provides a maximum reflectivity of 80%, although this can easily be increased by adding additional layers. Six GaSb QWs of thickness 8 nm with 8 nm AlSb barrier layers were grown on

CTuP31   Fig. 1   Time-resolved saturation and recovery of the exciton resonance feature at 1.55 µm for a peak pump intensity of 90 MW/cm^2; also indicated are the responses at 1.46 and 1.63 µm.

the surface of the Bragg mirror, followed by a cap layer of AlGaSb to protect the surface from oxidation; the MQWs gives rise to a heavy-hole exciton absorption peak at 1.55 µm. Bulk GaSb is a weakly direct gap semiconductor with a 70 meV separation between Γ and L conduction band edges. Confinement effects are expected to make the two edges nearly degenerate for our well widths. Our experiments employed a standard pump-probe reflection geometry. The optical source is a Coherent Laser Systems model 9800 optical parametric generator, providing 150-fs pulses at 250 KHz, with 60 nJ/pulse. Time-resolved reflectivity measurements for pump/probe wavelengths between 1.4 and 1.65 µm were carried out at room temperature.

Figure 1 shows that the transient reflectivity changes at 1.55 µm for a 90 MW cm^{-2} peak pump intensity. The partial saturation of the exciton resonance is followed by a two component recovery with time constants of 600 fs and ~12 ps. The former is attributed to exciton ionization as induced by zone center LO phonons or perhaps even zone-boundary phonons taking electrons into L-valley states. The longer time constant may reflect carrier recombination or evolution of exciton screening characteristics as free carriers cool. No significant pump induced change in reflectivity is observed for pump photon energies below the exciton energy as expected. Direct activation of continuum states by 1.45 µm photons yields a trace that is similar to that shown at 1.55 µm, although the peak of the signal is nearly 10 × smaller and temporally shifted. Similarity of the temporal characteristics of the two traces indicates that free carrier kinetics probably dominate exciton saturation recovery. Figure 2 shows that the exciton resonance is saturated at a peak intensity of 25 MW cm^{-2}; this intensity is close to what might be expected based on the need to provide one photon per exciton during its 600 fs lifetime and using an exciton radius of 11 nm for the 2-D structures.[2]

The fast recovery and favorable saturation characteristics point to application of these nonlinear mirrors as modelocking element in high-repetition-rate, short-pulse solid-state lasers operating at 1.55 µm. Unlike other III-V based materials, to reduce recovery time the GaSb/AlSb system does not require extra ion implantation or low temperature growth procedures that can degrade sample quality. The