Picosecond pulse generation with a cw GaAlAs laser diode[a)]

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We report the generation of 20-ps optical pulses at microwave repetition rate from a GaAlAs double-heterostructure diode operating cw at room temperature. The diode is operated in an external optical resonator and is actively modulated at 3 GHz. The pulses are measured by autocorrelation using SHG in $LiIO_3$. They are the shortest pulses ever reported for a cw laser diode.

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Picosecond optical pulse sources[1] have been playing an increasingly important role in the study of ultrafast processes and have potential application to high-speed electronics[2] and optical communications. Interest in picosecond techniques has recently been stimulated by the generation of ultrashort pulses at high repetition rate,[3] but conventional sources have remained large and cumbersome laboratory systems. We report here the operation of a compact picosecond pulse generator based on the cw GaAlAs double-heterostructure diode laser.

Studies of pulse generation from laser diodes were begun soon after the invention of the semiconductor laser diode. Most of this work was done on non-cw diodes and concerned with laser diode self-pulsing and attempts at controlling it to achieve reproducibility.[4-7] In one previous experiment weak mode locking of a GaAs diode laser in an open resonator was reported to generate pulses of 2 ns duration.[8] The work reported here was begun because the development of the double-heterostructure stripe geometry diode has improved diode performance to a degree such that renewed attempts at mode locking had a greater chance of success, because the understanding of mode locking has progressed sufficiently to provide a set of parameter ranges for which successful mode locking could be expected,[9] and last, but not least, because compact laser systems producing short optical pulses have obvious practical applications.

If the modulation of the laser diode optical gain is to contribute effectively to mode locking, the relaxation time of the population inversion in the diode requires operation of the diode in an external resonator. On the other hand the resonator should be kept short enough to prevent spontaneous emission from building up between pulses, a problem encountered in the work of Ref. 8. For these reasons the cavity round-trip time was chosen to be on the order of 1 ns. With such a system it became clear that the simplest method of pulse production was modulation of the diode injection current at a period corresponding to the cavity round-trip time. This is the system reported here.

The system is shown in Fig. 1. The laser diode[10] is uncoated on both output surfaces and is placed near the center of curvature of the external silver mirror. The mirror is spherical and has a radius of 5 cm. The composite resonator consists of three reflecting surfaces which include the external mirror and the two diode cleavage planes.

The isolated laser diode has a threshold current of 190 mA; the output wavelength is centered near 810 nm and is divided between several longitudinal modes 3.17 Å apart. The composite resonator reduces the threshold to 145 mA and the emission linewidth to no more than 0.5 Å, as measured by a grating spectrometer. There are, however, multiple external resonator modes present as evidenced by a 3 GHz $=c/2L$ beat signal on the microwave spectrum analyzer. There is a dramatic spectral narrowing of this microwave beat as the modulation of the diode current is tuned to resonance. On the other hand, the full optical spectrum, observed by the scanning Fabry-Perot, is broadened into several internal diode modes as the result of microwave modulation.

Microwave modulation was applied to the laser through a bias tee. Impedance matching was achieved by a shunt capacitance wired in cascade with a 50-Ω microstrip line which was terminated by the diode.

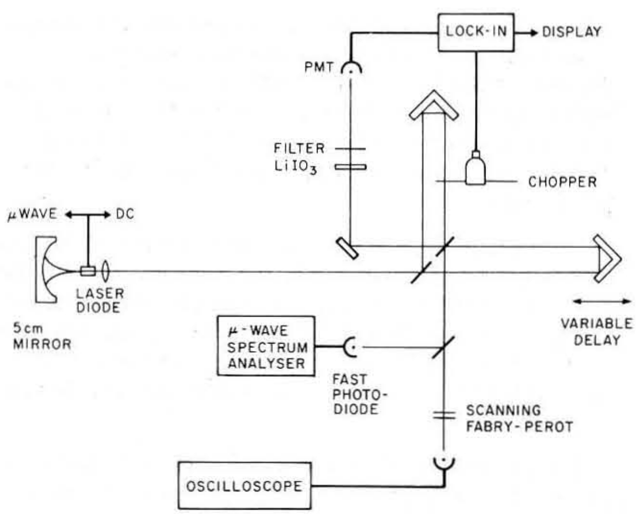

FIG. 1. Schematic of mode-locked laser and measurement system.

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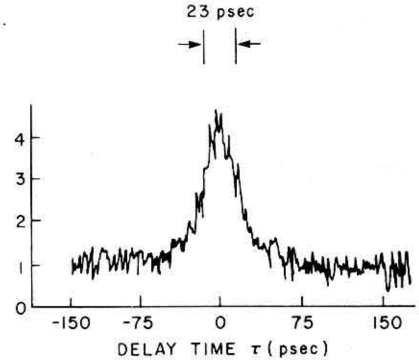

FIG. 2. Intensity autocorrelation trace through SHG.

The 3-dB matching bandwidth was 50 MHz. No more than 6 mW of microwave drive was used in this experiment.

The output of the laser is directed to an optical intensity correlator. Intensity correlation is made using phase-matched second harmonic generation (SHG) in a $LiIO_3$ crystal. The two fundamental (infrared) beams incident on the $LiIO_3$ crystal are approximately collinear and have relative intensities 8 : 5. The weaker beam is chopped when correlation measurements are made.

Figure 2 shows an experimental curve. The pulse duration is 23 ps (FWHM) assuming a Gaussian pulse shape. Some contrast is lost in the autocorrelation measurement because of spatial inhomogeneities in the beams. The contrast ratio is still greater than 3 : 1 because only one of the beams is chopped. In the absence of active mode locking the autocorrelation trace broadens and decreases dramatically in contrast and amplitude. Coherence spikes with the periodicity of the diode round-trip time (6.8 ps) are evident on the correlation trace, though not well resolved. This is due to spectral broadening into several internal diode modes as the modulation is turned on (Fig. 3). The exact mechanism of this excess broadening, observed also in forced mode-locked dye lasers,[11] is not well understood.

dc drive currents between 150 and 200 mA did not change the pulse width significantly. For fear of destroying the laser diode, 200 mA was never exceeded with modulation on. Alignment of the laser with the external mirror is relatively critical in obtaining reliable operation. This is accomplished by piezoelectric control.

The failure of previous attempts to mode lock diode lasers has been attributed to the dispersion of the laser material.[5] Our estimates based on measurements of cavity mode spacings in these double-heterostructure diodes indicate that such effects are no worse than those introduced by the prism in the mode-locked dye laser.[3]

The production of reproducible and controlable cw pulses from a semiconductor laser diode in a physically compact and rugged system opens up new possibilities for high-rate signal processing systems.

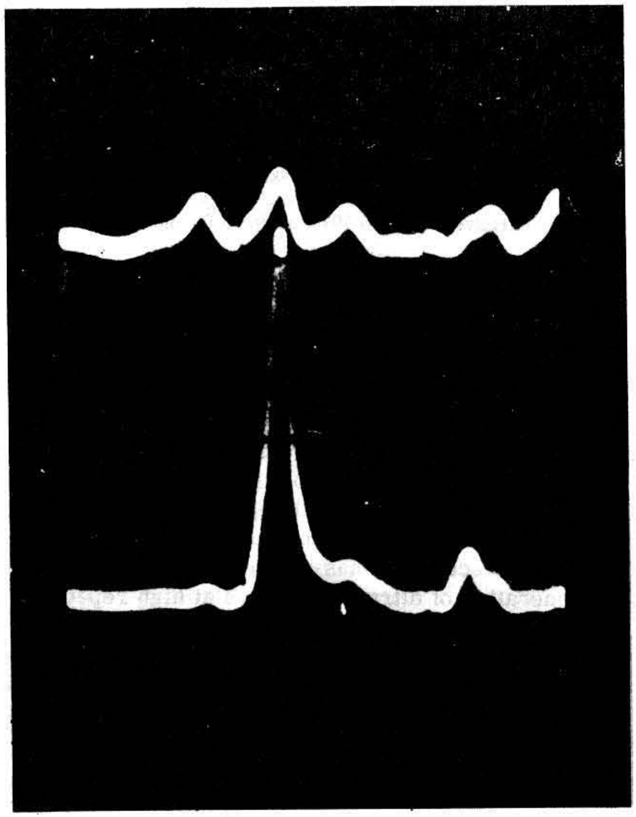

FIG. 3. Optical spectra; upper trace with modulation; lower trace without modulation.

Additional compactness may be obtainable by the use of optical waveguides or fiber guides once the loss of the former is reduced or the coupling problem of the latter is solved. Known principles may be used to multiplex and demultiplex pulses of 20 ps duration at 3 GHz rates.

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