C.W. MODELOCKING OF A GaInAsP DIODE LASER

Indexing term: Semiconductor junction lasers

Active c.w. modelocking of a GaInAsP double-heterostructure laser diode operating in an external cavity is reported. 18 ps pulses (f.w.h.m.) are obtained at a repetition rate of 2·1 GHz and a lasing wavelength of 1210 nm. The pulses were measured by autocorrelation using s.h.g. in $LiIO_3$. They are the shortest pulses ever reported for a c.w. laser diode.

Introduction: Picosecond pulse generation at microwave repetition rates may provide new capabilities for fast electronics, optical communication and electro-optic instrumentation. The recent successful modelocking of a GaAlAs laser diode[1] encouraged our group to attempt modelocking a GaInAsP laser diode. This quaternary system is important for its ability to match the wavelength regions where high-performance optical fibres are available. In addition, it was important to demonstrate that the techniques used to modelock a GaAlAs laser were transferable to other laser-diode systems.

In this letter, we announce the first successful modelocking of a c.w. GaInAsP laser diode. 18 ps pulses f.w.h.m. were obtained in a forced modelocking system similar to that of Ho *et al.*[1] Ours are the shortest pulses ever generated from a c.w. diode laser. Self locking was also observed.

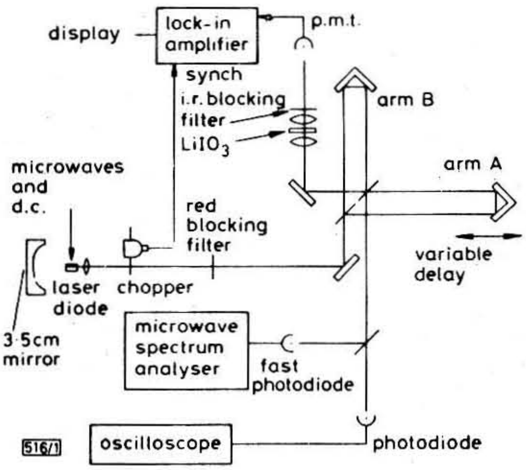

Fig. 1 *Schematic of modelocked laser and pulse-measurement system*

System description: The experimental arrangement is shown in Fig. 1. The modelocked laser on the left consists of a $Ga_{0\cdot21}In_{0\cdot79}As_{0\cdot48}P_{0\cdot52}$ c.w. laser diode[2] mounted near the centre of curvature of a spherical silver mirror of radius 3·488 cm. Contrary to our initial expectations, the pulse repetition rate corresponded to a cavity length of nearly 7 cm. This effect was observed by performing a cross correlation of the nth pulse with the $n + 1$ pulse. A large 2·1 GHz signal was also observed on the microwave spectrum analyser. We speculate that a second reflecting surface in juxtaposition to the diode's active area is illuminated, causing the cavity round-trip time to double. This phenomenon is encouraged by the image-inversion property of spherical mirrors. The lasing wavelength is 1210 nm. The external mirror reduces the threshold from 170 mA to 149 mA. The microwave and d.c. drives are combined in a bias tee to provide the forcing signal for the diode. The microwave drive frequency corresponds to the second harmonic of the cavity round-trip frequency.

The output is obtained through a microscope objective and directed into the intensity correlator shown on the right. Pulse-length measurements were carried out in a standard manner[3,4] by second-harmonic generation (s.h.g.) in phase-matched $LiIO_3$. This is the first demonstration of nonlinear mixing from a GaInAsP laser-diode source. The red blocking filter shown in Fig. 1 was necessary to keep the weak second harmonic generated in the laser diode[5] out of the photomultiplier tube.

Results: Fig. 2 shows two correlation traces taken with the system shown in Fig. 1. Fig. 2*a* shows the self-locking behaviour of the diode laser aligned in the external cavity and biased near threshold. The correlation curve of a pulse train with noise substructure is composed of three domains that may be interpreted once the s.h.g. due to each correlation arm is known separately. The s.h.g. intensity due to the movable arm A when arm B is blocked is labelled on the ordinate as A and similarly with the fixed arm B. In the wings where there is no pulse overlap, the intensities add linearly $(A + B)$. As one can see, the trace in Fig. 2*a* exhibits a slightly nonideal behaviour, which may be accounted for by a 10% optical background between pulses. At $\tau = 0$ the correlation reaches $A + B + 4\sqrt{AB}$ owing to the coherent addition of the fields. In the intermediate condition, noisy pulses add statistically yielding a height of $A + B + 2\sqrt{AB}$. Fig. 2*a* corresponds to 27 ps pulses f.w.h.m. assuming a Gaussian pulseshape.

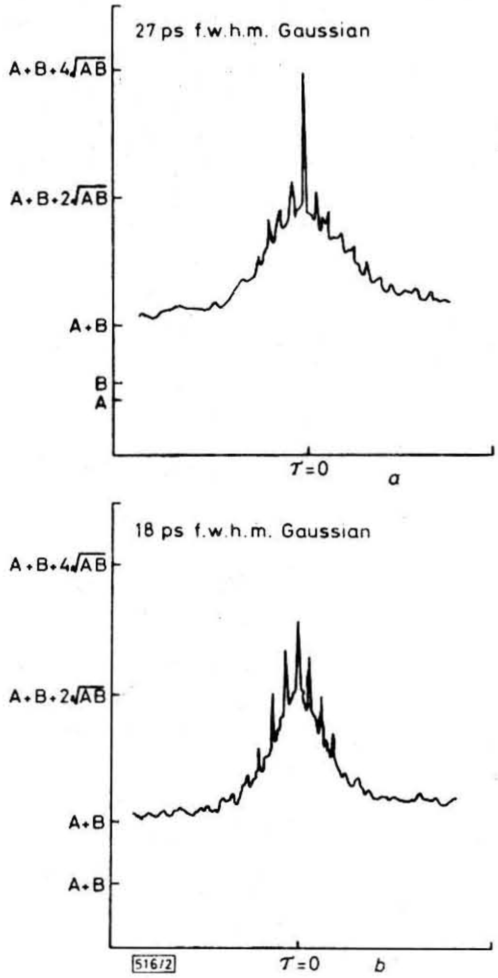

Fig. 2 *Intensity autocorrelation traces through s.h.g. for self-locking (a) and active modelocking (b)*

Fig. 2*b* shows a correlation trace taken when the microwave drive was used to actively modelock the laser diode. The dominant sidelobe spikes in this trace are due to the strong excitation of several internal laser-diode modes[1] (no antireflection coating was used). The trace in Fig. 2*b* corresponds to 18 ps f.w.h.m. for Gaussian pulses with noisy substructure and a repetition rate of 2·09 GHz. The integration time constant for this trace was 1 s, which when coupled with the scan rate, caused the correlation peaks to be incompletely resolved. Lower integration times led to noisier data but an almost ideal contrast ratio. In addition, though Fig. 2*b* shows some optical background between pulses; traces with immeasurable quantities of light between pulses were obtainable by optimising the external cavity alignment.

Conclusions: We have demonstrated c.w. modelocking of a GaInAsP laser operating in the wavelength region where

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low-loss and low-dispersion optical fibres exist.[6,7] We have shown that the mode-locking approach taken by Ho *et al.*[1] may be successfully extended to other laser-diode systems.

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