MODULATION AND SYNCHRONIZATION OF THE EMISSION OF A SEMICONDUCTOR INJECTION LASER

V. I. Magalyas, A. A. Pleshkov, L. A. Rivlin, A. T. Semenov, and V. V. Tsvetkov
Submitted 18 May 1967
ZhETF Pis'ma 6, No. 3, 550-552 (1 August 1967)

Self-modulation of the emission of a semiconductor injection laser [1], which becomes manifest in the form of spontaneous rise and fall of the intensity, with characteristic times to 10^{-11} sec, is evidence of the feasibility of generating very short trains of coherent light by injection with current pulses of much longer duration. When this possibility was realized, single pulses of light were observed [2] with duration close to 2×10^{-10} sec at an injection duration of 2×10^{-9} sec.

It is obvious that it is possible to obtain in similar fashion also a regular sequence of short light pulses separated by longer pauses, if the injection current is periodic (in the simplest case - sinusoidal) in time, with a frequency that determines the pulse repetition frequency. We present in this communication the results of experiments on such a high-frequency modulation of laser GaAs diodes obtained by the diffusion method. The experiment was performed in a vacuum cryostat with liquid nitrogen, using a space-time analyzer based on an electron-optical converter [1] with maximum resolution 5×10^{-12} sec.

It must apparently be regarded as established that the observed phenomena of self-modulation [1] and the shortening of the generation time relative to the injection time [2] are connected with the spatial inhomogeneity of the latter and are analogous to the trigger processes in the well-known quantum generators of powerful single pulses with phototropic filters [3-5 and elsewhere], the role of the saturating resonance absorbers being assumed by the sections with reduced injection density.

Starting from this, we can predict two extreme cases of modulation: with sufficiently uniform and with highly uneven injection.

In the former case, the electron density duplicates in time the variation of the injection current, but with a smaller depth of modulation and with a certain phase lag. For example, if the density of the injection current is of the form $j_0(1 - \cos \omega\tau\theta)/2$, where j_0 is the amplitude, ω the cyclic modulation frequency, τ the spontaneous recombination time, and $\theta = t/\tau$ the running dimensionless time, then the electron density (without the lasing regime) depends on the time like $n = Aj_0/2\ [1 - \cos(\omega\tau\theta - \phi)/\sqrt{1 + (\omega\tau)^2}\ ]$, where $\theta < \phi = \tan^{-1}\omega\tau < \pi/2$ is the phase shift and A is a constant, from which we see that increasing the modulation frequency and compression of the pulse relative to the injection cycle are obtained at the cost of lowering the ac component of the emission intensity (the excess of n over the threshold n_{thr}) and the depth of modulation. (Thus, in the experiments of [6], where the parameter $\omega\tau$ was of the order of 30, the depth of the radiation modulation, estimated with the aid of a traveling-wave photomultiplier and a superheterodyne, was only several per cent.) Figure 1a shows the time sweep, on the electron-optical-converter (EOC) screen, of the laser emission during the course of such a modulation process with depth 100%, compression $T/(2\pi/\omega) \approx 0.5$ ($\omega/2\pi = 0.5$ GHz) and an excess above threshold by an approximate factor of 2.

An example of the other extreme case is a diode with isolated injection regions [7], in which the self-modulation regime is established particularly distinctly [8] at different injection densities in each region. As indicated earlier, the very short durations of the pulses of emission from diodes with uneven injection are connected with the triggerlike character of the processes occurring in them. Therefore the presence of a periodic component in the injection current determines not so much the intensity and depth of the modulation and the duration of the pulses, as the instants of their occurrence. The modulation is in essence converted into synchronization. This phenomenon is demonstrated on the adjacent photographs of the time sweeps of the laser emission from a diode with isolated injection regions, as exhibited on the EOC screen.

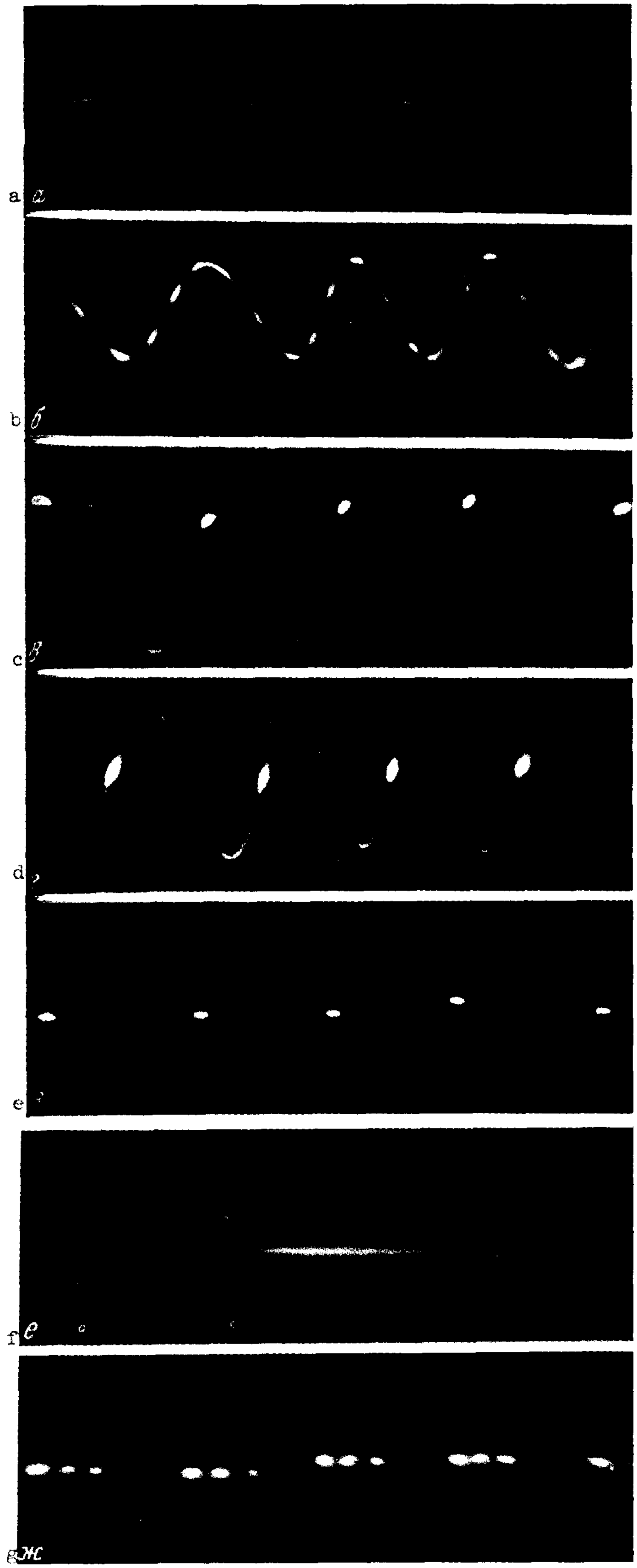

Figure 1b shows the free self-modulation radiation of the diode with isolated regions in the case of unmodulated injection with a sinusoidal time-calibration signal ($\omega/2\pi = 0.5$ GHz), fed to the second pair of the EOC deflection plates (excess over threshold by a factor of 2).

Figure 1c shows the synchronization of the radiation pulses from the same diode, following injection of a current having approximately equal dc and ac components (sinusoidal signal of frequency $\omega/2\pi = 0.5$ GHZ, equal to the frequency of the time-calibration signal). We see that the phase of the pulse is fixed relative to the injection current, and that the phase is shifted forward when the dc component of the inection is increased by 20% (Fig. 1d).

Fig. 1e shows the same but without the sinusoidal time-calibration signal. The compression $T/(2\pi/\omega)$ amounts to about 0.07 at a pulse duration $T < 0.15$ nsec. Figure

1f shows the structure of an individual radiation pulse swept with a resolution 5×10^{-12} sec. Figure 1g shows that when the dc component of the injection current is doubled only the first pulse in the group is synchronized, and the succeeding pulses have a self-modulation character. The pauses between the groups decrease with increasing dc component of the current, and gradually free self-modulation sets in when the dc component greatly exceeds the sinusoidal injection current. A convenient method of eliminating the dc component and at the same time protecting the diode against breakdown at large inverse sinusoidal injection currents is to connect two diodes in antiparallel.

It should be noted in conclusion that the regular sequences of light pulses obtained by synchronizing semiconductor-laser emission by sinusoidal injection current have the following useful properties, which are not possessed by the self-modulation regime: The repetition frequency ω of the pulses and their phase are rigidly controlled by the external signal and are independent to a considerable degree of the diode properties, which vary from sample to sample with time (aging), and also of the external parameters. The repetition frequency ω and the pulse duration T are not interrelated, making it possible to vary independently the ratio $T/(2\pi/\omega)$ down to very low values.

[1] V. D. Kurnosov, V. I. Magalyas, A. A. Pleshkov, L. A. Rivlin, V. G. Trukhan, and V. V. Tsvetkov, ZhETF Pis. Red. 4, 449 (1966), JETP Lett. 4, 303 (1966).

[2] V. D. Kurnosov, A. A. Pleshkov, G. S. Petrukhina, L. A. Rivlin, V. G. Trukhan, and V. V. Tsvetkov, ibid. 5, 77 (1967), transl. p. 63.

[3] L. A. Rivlin, Zh. Eksp. Teor. Fiz. 47, 624 (1964), Soviet Phys. JETP 20, 416 (1965).

[4] G. Bret and Fr. Gires, Appl. Phys. Lett. 4, 175 (1964).

[5] V. I. Borodulin, N. A. Ermakova, L. A. Rivlin, and V. S. Shil'dyaev, Zh. Eksp. Teor. Fiz. 48, 845 (1965), Sov. Phys. JETP 21, 563 (1965).

[6] B. S. Goldstein and R. M. Weigand, Proc. IEEE 53, 195 (1965).

[7] G. J. Lasher, Solid State Electron. 7, 707 (1964).

[8] Yu. A. Droshbin, Yu. P. Zakharov, V. V. Nikitin, A. S. Semenov, and V. A. Yakovlev, ZhETF Pis. Red. 5, 180 (1967), JETP Lett. 5, 143 (1967).

ANTHRACENE LUMINESCENCE QUENCHING BY A MAGNETIC FIELD

E. L. Frankevich and B. M. Rumyantsev
Institute of Chemical Physics, USSR Academy of Sciences

Submitted 29 May 1967
ZhETF Pis'ma 6, No. 3, 553-556 (1 August 1967)

Investigations [1-4] of the photoconductivity of anthracene single crystals and of its variation in a magnetic field have led to the conclusion [2] that there exist in anthracene excitons (Π) of large radius (with charge transport or of the Wannier type), whose lifetimes depend on the magnetic field (as a result of the mixing of the Ψ-functions of the singlet Π_1 and triplet Π_3 states of the excitons). The excitons Π_1 and Π_2 are produced in the anthracene, according to [2-4], when the holes and electrons generated by the light recombine. It is also known that the recombination of the holes and electrons within the volume of single-crystal anthracene is accompanied by luminescence due to radiation by singlet molecular excitons M_S^* [5].

The aforementioned results of [2-4] and [5] differ from each other. Their comparison leads to the conclusion that differences should exist in the conditions of exciton production as well as a definite connection between the large-radius Π excitons and the molecular M^*