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A Crossed-Beam Optical Gate with a Saturable Absorber (*).

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A saturable absorber such as a solution of vanadium phtalocyanine in nitrobenzene driven by a giant ruby laser pulse can be used in fast optical gate or coincidence experiments. The transmission T of a cell containing the bleachable solution depends on the power density of the input light pulse.

Taking a simple two-level model which neglects the contribution of a third intermediate metastable level (1) and considering an optically thin cell radiated by a steplike optical pulse of power density $h\nu\Phi$, the steady state transmission T is given by

$$(1)\qquad T = \exp\left[-\frac{\sigma L N}{1+2\Phi\sigma/\gamma}\right],$$

where N is the number of molecules per cm^3, σ is the interaction cross-section for the material at the laser wavelength (slightly different from the peak of the absorption curve which occurs at 6970 Å), γ is the spontaneous decay rate from the upper level and L is the length of the absorbing cell in the direction of the impinging light. A calculation which takes into account the finite thickness (2) (**) does not yield substantial differences in shape with respect to (1).

A critical value $\Phi_{cr} = \gamma/2\sigma$ of photon flux can be considered, below which the transmission is practically the low-level linear transmission and above which saturation effects become important giving a steep rise in the T *vs.* Φ curve. Taking the following measured values (3) for input light at 6943 Å.

$$\sigma = 0.30\cdot 10^{-15}\ \text{cm}^2, \qquad \gamma = 1.9\cdot 10^{8}\ \text{s}^{-1},$$

the power corresponding to Φ_{cr} results to be $8\cdot 10^4\ \text{W/cm}^2$. This is actually the order of magnitude of Φ_{cr} observed experimentally.

The experimental set-up is shown in

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(1) P. P. SOROKIN, J. J. LUZZI, J. R. LANKARD and G. D. PETTIT: *IBM Journ. Res. and Develop.*, 8, 182 (1964).

(**) We have modified the calculation of ref. (2) taking into account spontaneous decay rate.

(2) L. M. FRANTZ and J. S. NODVIK: *Journ. Appl. Phys.*, 34, 2346 (1963).

(3) F. T. ARECCHI, V. DEGIORGIO, G. POTENZA and A. SONA: unpublished work.

Fig. 1. A Q-switched ruby laser is used to produce the saturating pulse. The output pulse has a peak power of 1.5 MW and 25 ns duration at half-height, with a beam cross-section of 0.3 cm^2 corresponding to a maximum power density of 5 MW/cm^2. The probe pulse crossing the cell at 90° is derived from the main pulse by a beam splitter and is attenuated below the critical power down to 10^3 W/cm^2, to avoid self-saturation effects. The interaction cell has one

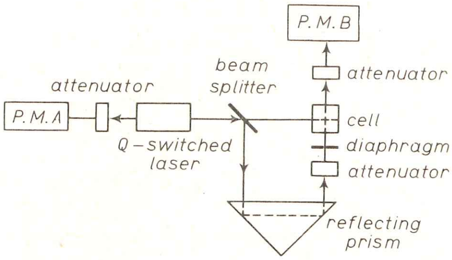

Fig. 1. – Experimental set-up.

dimension (the one perpendicular to the saturating beam) equal to the diameter of the beam itself in order to reduce non-saturated regions and a length $L = 0.7$ cm. The probe beam intensity is monitored by the phototube B; a second phototube A is used to correct for amplitude fluctuations in the laser pulse.

In Fig. 2 the transmission factor T with the saturating pulse *ON* is plotted *vs.* the transmission factor T_0 without saturating pulse (*i.e.* *vs.* the low-level transmission factor which is related to the concentration). Both T and T_0 are normalized to the transmission of the cell when containing pure nitrobenzene. The three curves *a*), *b*) *c*), correspond to the decreasing values of the specific power obtained inserting attenuators in the saturating beam. The used values of Φ are

$$h\nu\Phi_a = 5\ \text{MW/cm}^2,$$

$$h\nu\Phi_b = 500\ \text{kW/cm}^2,$$

$$h\nu\Phi_c = 30\ \text{kW/cm}^2.$$

As Φ_c is close to the critical value only small departures from linearity can be observed in curve *c*.

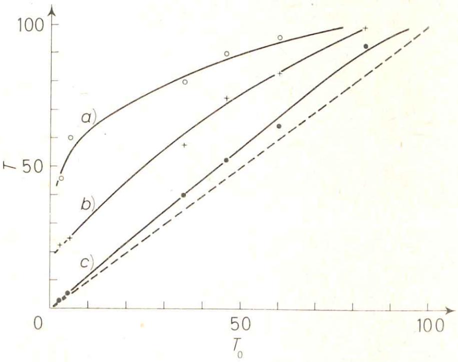

Fig. 2. – Transmission factor T with saturating pulse on *vs.* transmission factor T_0 without saturating pulse. Saturating pulse power density: *a*) 5 MW/cm^2; *b*) 500 kW/cm^2; *c*) 30 kW/cm^2

In Fig. 3 the ratio $R = T/T_0$ is plotted *vs.* T_0. R represents the rejection factor of the optical gate, *i.e.* the ratio between the open-gate and the closed-gate transmission. Values of R as high as 20 have been obtained in correspondence to the highest values of saturating power and

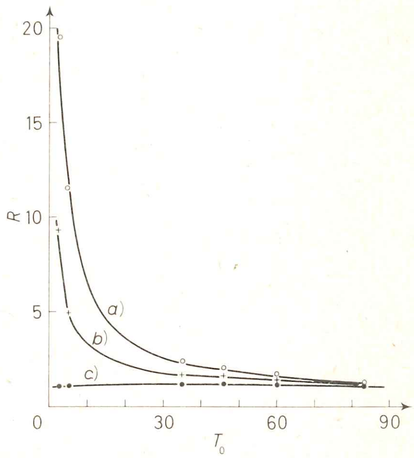

Fig. 3. – Optical gate rejection factor $R = T/T_0$ *vs.* low-level transmission factor T_0, for different values of saturating pulse power: *a*) 5 MW/cm^2; *b*) 500 kW/cm^2; *c*) 30 kW/cm^2.

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concentration. In this condition the transmission obtained in the open-gate case is about 50% of that obtainable by complete bleaching.

Delayed coincidence experiments have been also performed to measure the time at which the optical gate closes. Prism P was placed at different distances in order to obtain different delays between saturating and probe pulse. The results are summarized in Fig. 4 for

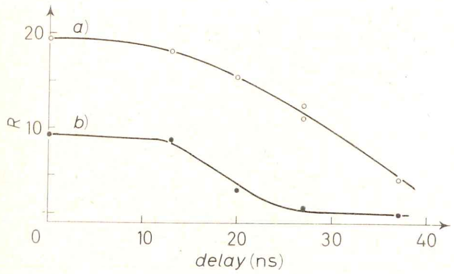

Fig. 4. – Optical gate rejection factor $R = T/T_0$ *vs.* time for different values of saturating pulse powers: *a*) 4 MW/cm²; *b*) 300 kW/cm².

two different values of power density $P_a = 4\ \text{MW/cm}^2 = P_b$ and $300\ \text{kW/cm}^2$ and for a solution with $T_0 = 2\%$. As expected, the time at which the gate closes (taken by convention as the point where the transmission has reduced to 20% of its maximum value) increases with the saturating pulse power and approximately coincides with the time at which the saturating pulse falls down to the critical power level, due to the rather short decay time constant from the upper level. Namely taking a Gaussian shape for the laser pulse, one calculates that the input level reaches the critical value at 36 and 21 ns from the peak for case *a*) and *b*) respectively, in good agreement with the experimental values.

The plots of Fig. 4 have been taken with a maximum delay of 37 ns between gating and gated pulse. In case *b*) the transmission has already reached the low-level value T_0 after 37 ns, and no appreciable effect (within 5%) of the third metastable level (1) is observed.

This experiment proves the feasibility of optical coincidence circuits both for logical operations on optical pulses as for analog operations similar to the ones performed by electronic linear gates (4). Although not essential for probe signals, laser light proves to be essential for the gating pulses because of its high directionality and specific power.

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(4) O. A. Reimann and W. F. Kosonocky: *IEEE Spectrum*, **2**, 181 (1965).

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