V. S. Dneprovskiĭ. *Optical bistability in semiconductors.* The phenomenon of optical bistability (OB) is determined by the totality of static and dynamic processes occurring in nonlinear systems with feedback. An optically bistable system can have two stable states for the output signal with one value of the input signal.[1] Optical bistability is of interest both from the practical point of view for creating inertialess optical transistors, switches, memory elements, and other optoelectronic devices[2] and for studying the nonlinear optical processes which determine the bistable behavior of systems: feedback permits registering the nonlinear process with relatively low levels of excitation. The most promising material for OB devices are semiconductors with high nonlinear susceptibilities.

An optically bistable element usually consists of a Fabry-Perot resonator filled with a nonlinear medium. The index of refraction of the material and, correspondingly, the optical path length of the resonator change under the action of the light flux. The transmission of the resonator becomes nonlinear (Fig. 1): regions of differential amplification, restriction, and hysteresis appear.[3]

We shall examine only the intrinsic[1)] OB in passive semiconducting systems, in which the nonlinearity is amplified by resonant processes. Due to the Coulomb interaction between electrons and holes in the semiconductor, one- and two-photon resonances, associated with the formation of excitons and exciton molecules, appear.

1. Optical bistability with an exciton resonance was observed in GaAs[4] and GaSe[3,5] Fabry-Perot resonators in the case when the wavelength of the exciting radiation is detuned from the peak of the exciton absorption line $\lambda > \lambda_{ex}$, $\lambda - \lambda_{ex} \simeq \Delta\lambda$, where $\Delta\lambda$ is the half-width of the line. In this case, "saturation" of the exciton transition, associated with inelastic exciton-exciton and exciton-electron scattering processes, scattering of excitons, and a Mott transition, oc-

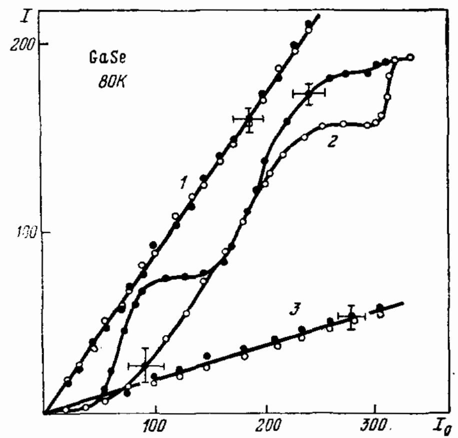

FIG. 1. Dispersion of the dependence of the radiation intensity at the output from a GaSe resonator (12 μm) on the intensity of radiation incident on the crystal.[3] 1) Region of transparency, 2) exciton resonance, 3) interband transitions.

curs.[1,6] The polarizability associated with the exciton resonance changes. As the level of excitation is increased, the index of refraction in the region $\lambda > \lambda_{ex}$ changes. The large nonlinearity associated with the exciton transition and the bistable state of etalons operating at room (!) temperature have been recorded in a superlattice in the system GaAs–GaAlAs[7] and in GaSe,[5] which has a high (20 meV) exciton binding energy.

2. When semiconductors interact with powerful radiation with a photon energy of $\hbar\omega_m/2$ ($\hbar\omega_m$ is the energy of the biexciton), biexcitons are efficiently created, since an almost resonant exciton transition participates in the process of two-photon excitation of exciton molecules.[8] The nonlinear growth of the coefficient of absorption and, correspondingly, of the index of refraction at the frequency $\omega_m/2$ at sufficiently high concentrations of polaritons permitted obtaining the bistable mode in high-Q CuCl etalons.[9,10]

3. The possibility of the appearance of optical hysteresis, arising due to the dependence of the depth of local impurity levels on the concentration of free carriers, was pointed out in Ref. 11. The positive feedback arises because of the decrease in the screening radius accompanying the ionization of the impurity centers. Optical bistability based on excitons bound on neutral donors was recently observed with a low ($\sim$ 1mW) level of excitation in CdS.[12]

4. Resonatorless absorption OB near a sharp exciton resonance ($\lambda > \lambda_{ex}$), associated with increasing nonlinear absorption ($\alpha(n)$) accompanying an increase in the level of excitation, was obtained by Rossmann *et al.*[13] and by Bohern *et al.*[14] The characteristic feedback appeared when the generation of particles dominated recombination.[15] The nonmonotonic growth of α accompanying the growth of the particle concentration n could be associated[15] with a Mott transition, increased damping in the region of the wing of the exciton absorption line, formation of exciton molecules, and renormalization of the width of the forbidden band[14] accompanying two-photon excitation of the plasma.

5. Optical bistability accompanying interband transitions has been observed in InSb,[16] Te,[17] InAs,[18] and GaSe[19] Fabry-Perot resonators. In narrow-band semiconductors this method of excitation is apparently most promising, since the nonlinear susceptibility increases markedly with a decrease in the width of the forbidden band. Optical bistability with interband transitions also appears in uncooled samples.[17,19,20] The nonlinear properties of semiconductors are determined by saturation processes, the Burshteĭn-Moss shift, and the absorption of free carriers by the plasma.[1] A new type of optical hysteresis with a common point of intersection of the stable states was recorded in GaSe etalons with interband absorption of continuous laser radiation.[19]

6. The effect of a light field on the anisotropy of the index of refraction near an exciton resonance of a CdS resonator and optical hysteresis have been observed by Vidmont *et al.*[21]

Several nonlinear processes can appear simultaneously in a bistable element. If nonlinearities of both signs, differing either by their time constants or by the dependence on the light intensity, exist in the system, then oscillations can appear in it.[11,22] Oscillations have been observed by Gibbs *et al.*[7] and Jewell *et al.* [22] in GaAs and GaAs–GaAlAs in the presence of two competing processes: "saturation" of excitons and thermal. The nanosecond pulsation mode (Fig. 2) has been obtained with the reflection of a light pulse from a GaSe etalon (300 K).

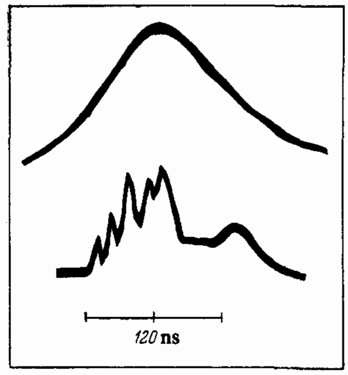

FIG. 2. Oscillograms of the light pulses ($I \approx 600$ kW/cm^2) incident on and reflected from a GaSe resonator (300 K). One of the 8-μm thick mirrors of the resonator has a coefficient of reflection of 100%; the other one has a natural cleavage surface. Obtained by A. M. Bakiev, G. S. Volkov, V. S. Dneprovskiĭ, and Z. D. Kovalyuk.

Optical bistability based on excitons at low levels of excitation in uncooled GaAs–GaAlAs[23] (excitation by a semiconductor laser) and GaSe[24] (excitation with a continuous laser) Fabry-Perot resonators has now been recorded, which opens up realistic possibilities for the use of semiconducting bistable elements in optoelectronics.

[1)] Feedback is created by the mirrors of the resonator or the nonlinear process itself and not with the aid of an external electronic device. The latter method is called hybrid.

[1] E. Abraham and S. D. Smith, Rept. Progr. Phys. **45**, 815 (1982).
[2] A. Abraham, K. T. Siton, and S. D. Smith, V mire nauki No. 4, 16 (1983).
[3] A. M. Bakiev, V. S. Dneprovskiĭ, Z. D. Kovalyuk, and V. A. Stadnik, Dokl. Akad. Nauk SSSR **271**, 611 (1983) [Sov. Phys. Dokl. **28**, 579 (1983)].
[4] H. M. Gibbs, S. L. McCall, T. N. C. Venkatesan, A. C. Gossard, A. Passner, and W. Wiegmann, Appl. Phys. Lett. **35**, 451 (1979).
[5] A. M. Bakiev, V. S. Dneprovskiĭ, Z. D. Kovalyuk, and V. A. Stadnik, Pis'ma Zh. Eksp. Teor. Fiz. **38**, 493 (1983) [JETP Lett. **38**, 596 (1983)].
[6] M. L. Stein-Ross and C. W. Gardnier, Phys. Rev. **A27**, 310 (1983).
[7] H. M. Gibbs, S. S. Tarng, J. L. Jewell, D. A. Weinberger, A. C. Gossard, S. L. McCall, A. Passner, and W. Wiegmann, Appl. Phys. Lett. **41**, 221 (1982).
[8] S. W. Koch and H. Haug, Phys. Rev. Lett. **46**, 450 (1981).
[9] R. Levy, J. Y. Bigot, B. Honerlage, F. Tomasini, and J. B. Grun, Solid State Commun. **48**, 705 (1983).
[10] N. Reyghambarian, H. M. Gibbs, M. C. Rushford, and D. A. Weinberger, Phys. Rev. Lett. **51**, 1692 (1983).
[11] T. S. Dneprovskaya, Phys. Status Solidi B **52**, 39 (1972).
[12] M. Dagenais and H. G. Winful, Appl. Phys. Lett. **44**, 574 (1984).
[13] H. Rossmann, F. Henneberger, and J. Voigt, Phys. Status Solidi B **115**, K63 (1983).
[14] K. Bohern, H. Kalt, and C. Klingshirn, Appl. Phys. Lett. **43**, 1088 (1983).
[15] F. Henneberger and H. Rossmann, Phys. Status Solidi B **121**, 685 (1984).
[16] D. A. Miller *et al.*, Appl. Phys. Lett. **35**, 658 (1979).
[17] G. Staupendahl and K. Schindler, Opt. and Quantum Electron. **14**, 157 (1982).
[18] C. D. Poole and E. Garmire, Appl. Phys. Lett. **44**, 363 (1984).
[19] G. P. Golubev, V. S. Dneprovskiĭ, Z. D. Kovalyuk, and V. A. Stadnik, Pis'ma Zh. Tekh. Fiz. **10**, 350 (1984) [Sov. Tech. Phys. Lett. **10**, 146 (1984)].

[20]A. K. Kar, J. G. H. Mathew, S. D. Smith, V. Davis, and W. Prettl, Appl. Phys. Lett. **42**, 334 (1983).
[21]N. A. Vidmont, A. A. Maksimova, I. I. Tartakovskiĭ and V. M. Édel'shteĭn Pis'ma Zh. Tekh. Fiz. **9**, 1527 (1983) [Sov. Tech. Phys. Lett. **9**, 654 (1983)].
[22]J. L. Jewell, H. M. Gibbs, S. S. Tarng, A. C. Gossard, and W. Wiegmann, Appl. Phys. Lett. **40**, 291 (1982).
[23]S. S. Tarng, H. M. Gibbs, J. L. Jewell, N. Peyghambarian, A. C. Gossard, T. Venkatesan, and W. Wiegmann, Appl. Phys. Lett. **44**, 360 (1984).
[24]G. P. Golubev, V. S. Dneprovskiĭ, E. A. Kisilev, Z. D. Kovalyuk, and V. A. Stadnik, Dokl. Akad. Nauk SSSR (1984).