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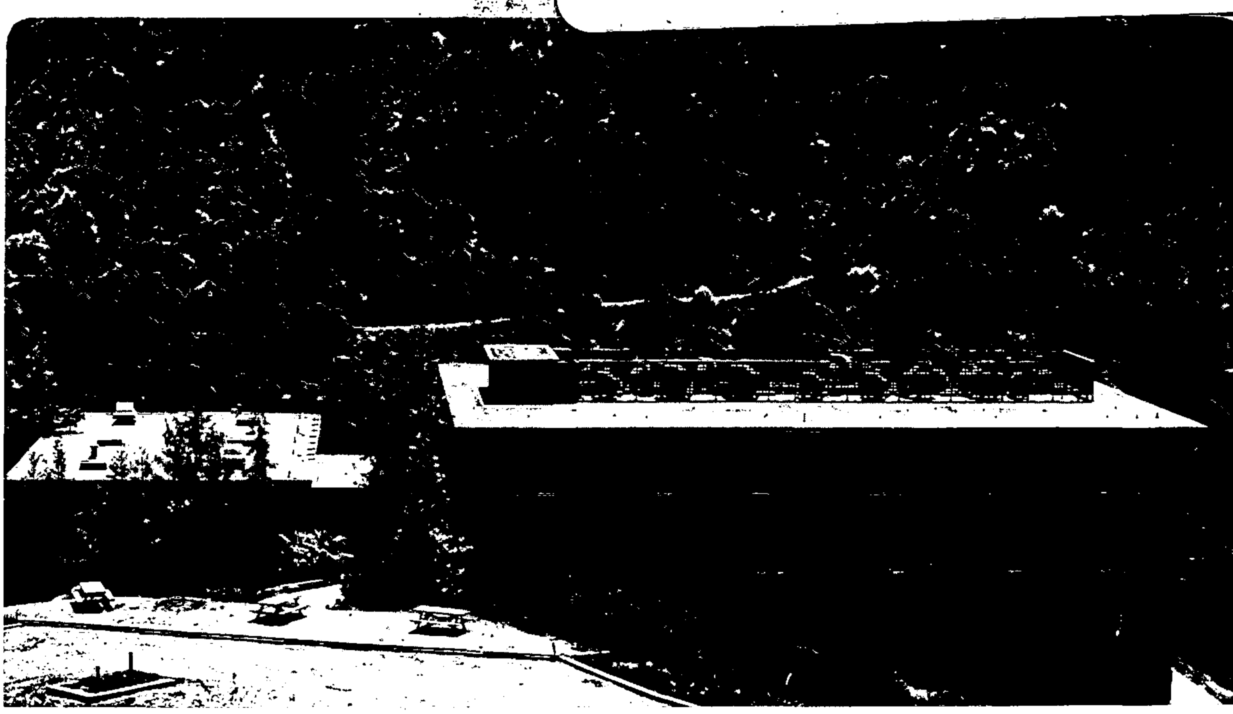

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RECENT ADVANCES IN OPTICAL BISTABILITY

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In recent years, optical bistability has been a subject of intense research in quantum electronics as it may someday find important applications in optical data processing and all-optical logic and computing systems.[1] There has already been a topic conference on the subject,[2] and at the recent XIIth International Quantum Electronics Conference in Munich (June, 1982), two sessions were devoted to the subject.

A system exhibiting optical bistability has its output versus input characterized by hysteresis loops; at a given input, the steady-state output can be either high or low depending on the operation path. The bistable characteristics are in fact the basis of a binary switching element. It was earlier predicted and demonstrated that an optical Fabry-Perot (F-P) interferometer filled with a nonlinear medium should exhibit bistability. The principle of the device, including the transient[3] and steady-state behavior[1] and its analog to phase transition,[4] is already fairly well understood. The more recent advances on the subject are mainly on materials and technology, but the following are particularly worth mentioning.

A most significant advance in the search of materials for nonlinear

F-P interferometers is the discovery of the superiority of the GaAs-GaAℓAs superlattice structure.[5] The future applications of optical bistability would require the development of small (~ 1 μm), fast (~ psec), low-operating-power (~ 1 μW), room-temperature devices. Semiconductors with an excitonic (a positronium-like entity in solid) line transition appear to be most promising because of the large nonlinearity associated with the very low power required to achieve saturation in absorption. Optical bistability has indeed been found to occur in a 4.1 μm etalon of pure GaAs with an input laser beam at the exciton frequency.[6] Unfortunately, excitons in GaAs dissociate above 120°K, while at low temperatures, the bistable switching time is long (~ μsec). Recently, it has been found that GaAs-$Ga_xA\ell_{1-x}As$ superlattices grown by molecular beam epitaxy can have a larger exciton binding energy than that of pure GaAs because of the quantum-well effect. As a result, excitons can exist in a superlattice even at room temperature. The power required for saturation of the exciton transition at room temperature is also three times weaker than that of pure GaAs. These features point towards the possible construction of a small, efficient optical bistable device. Indeed, on a 2 μm-thick etalon of GaAs (335 Å) - $Ga_{0.73}A\ell_{0.27}As$ (401 Å) superlattice at room temperature, optical bistability can be observed with a ~ 100 mW laser at the exciton frequency. The switching time is around 20-40 nsec. Further improvement can probably be made by using thinner layers in the superlattice structure.

In the earlier work, the ray approximation was always used in the analysis of the nonlinear F-P interferometer. Different sections of the beam would act independently in transmitting through the interferometer. With a Gaussian beam profile, the switch-up and down intensities would then be radially dependent. Actually, even in a medium with purely local response, different parts of the beam are coupled through diffraction. The effect is most significant in F-P cavities with large Fresnel numbers. In addition, the intensity-dependent transverse variation of the induced refractive index can distort the wavefront and lead to self-focusing or defocusing of the beam. Two papers have recently addressed the problem.[7] Their numerical calculations show that a strong coupling can result in a cooperative switch-up of practically the whole beam, and also in a much faster switching speed. The strong wavefront distortion can also give rise to an output with a multiple-ring pattern.

As a device with positive feedback, the stationary response of a bistable optical system may become unstable. The instability could lead to periodic oscillation, bifurcation, and chaos, a subject of great current interest to many scientists in different disciplines. Ikeda has recently spelled out, with some help of numerical calculations, the detailed conditions for the instability.[8] Although his theory uses the model of a ring cavity, it is believed that the results should also apply, at least qualitatively, to the F-P interferometer. Instability, bifurcation, and chaos have actually been observed in a F-P interferometer with electronic feedback controlling the nonlinearity of the medium.[9] The experimental results are most useful as a test of the theory of chaos. Chaotic output from an all-optical nonlinear F-P interferometer would be even more interesting, but has not yet been realized.

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