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# Optical bistability in second order nonlinear media: II. Ferroelectrics (experimental results)

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In this paper, some experimental results concerning optical bistability in a ferroelectric crystal ($BaTiO_3$) are presented. A strong laser beam interacts nonlinearly with the material and influences a second (probe) beam in such a way that its transmitted part exhibits bistable dependence on the intensity and the polarization of the first beam. It has been observed that such a character may be attributed to intensity as well as to polarization of outgoing probe wave. The results obtained reflect the symmetry of the sample which strongly depends on the temperature.

## 1. Experiment

In this work, we continue investigation of the optical bistability, reported in the first part of the lecture (this volume), by using another kind of materials exhibiting nonlinear behaviour, namely barium titanide ($BaTiO_3$), which in room temperature is a typical ferroelectric. In such substances one can expect nonlinearity of second order, in particular, optical bistability [1], [2]. The aim of our experiment was to check the possibility of such effects occurring in real samples.

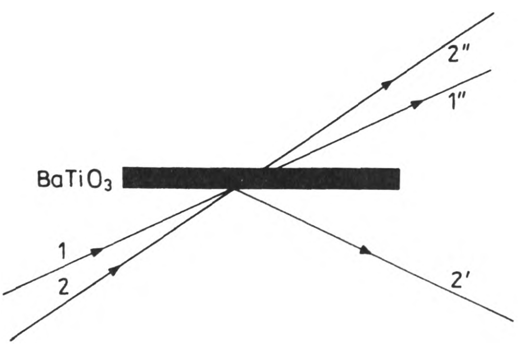
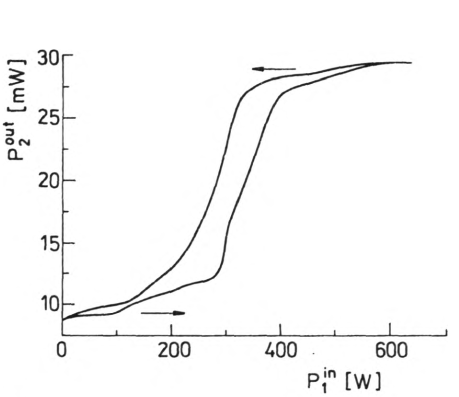


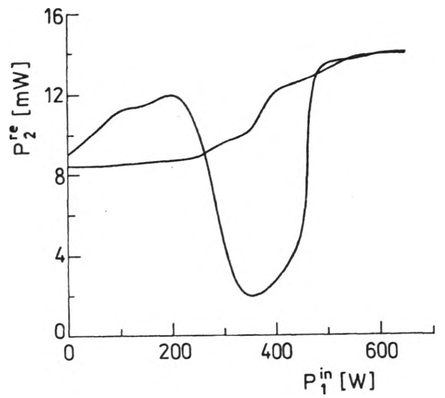

Fig. 1. Experimental setup

The experimental setup is practically the same as described in the previous paper. The only difference is that we now use a plate of $BaTiO_3$ instead of NCL film (Fig. 1). The thickness of the plate was of the order of 0.1 mm. We also used the same laser: argon-ion (LEXEL 3500) and helium one of much smaller power.

## 2. Results

The transmitted red light was measured as a function of the intensity of the original green beam. This dependence is presented in Fig. 2. It has been observed that $P_2$ grows abruptly with increasing $P_1$, roughly, at $P_1 \approx 0.3$ W. By decreasing $P_1$ a similar jump (down this time) appears at $P_1 \approx 0.2$ W. This means that the width of the bistable loop is about 0.1 W. More spectacular is the height of this loop. In all the cases considered it reaches more than 50% of the initial value.




▲
Fig. 2. Bistable loop of the transmitted (red) wave intensity

Fig. 3. Dependence of the reflected (red) wave intensity on the incident (green) wave intensity

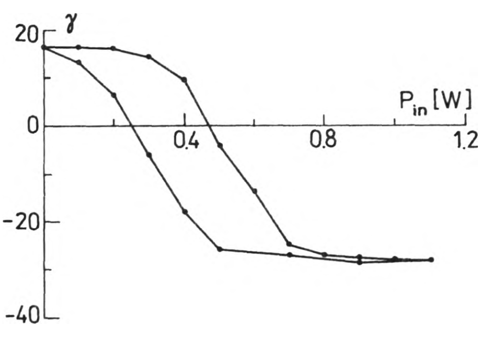



Fig. 4. Bistable loop of the parameter $\gamma$

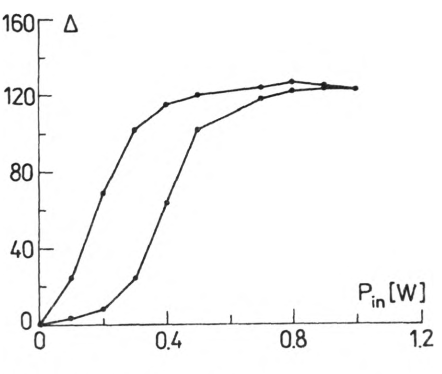



Fig. 5. Bistable loop of the parameter $\Delta$

The reflected part of the red wave exhibits also bistable character but the shape of the bistable loop is, of course, different (Fig. 3), being complementary to the transmitted loop.

The polarization of the green light has significant influence on the shape of both curves. Maximal effect appears when vector $\boldsymbol{E}$ of this beam is parallel to the plane

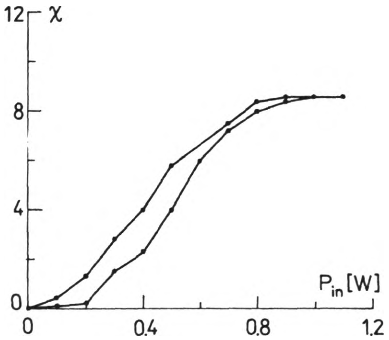



Fig. 6. Bistable loop of the parameter $\chi$

of incidence; this is just the case shown in Figs. 2, 3. For higher values of the polarization angle the bistable loop gets smaller and finally disappears for $\boldsymbol{E}$ parallel to the surface of the sample.

The next three figures are connected with another kind of bistability, which relates to the polarization state of the transmitted (red) wave. It is usually represented by four quantities called Stokes parameters $S_0$, $S_1$, $S_2$ and $S_3$ [3]. They may be expressed by three other parameters ($\gamma$, $\Delta$ and $\chi$) describing the polarization ellipse. Here, $\gamma$ is connected with the ratio $\pm b/a$ of half-axes, $\Delta$ is the phase difference of both components, $\chi$ corresponds to the angle between the longer axis and $0x$ axis. Two signs in $\gamma$ indicate two directions of circulation on the ellipse.

It has appeared that all these parameters may exhibit bistable behaviour. Figures 4–6 show their dependence on the intensity of the strong (green) laser beam. No hysteresis loops were observed in room temperatures. They appeared only after heating the sample to the temperature close to 146 °C. At such a temperature, $BaTiO_3$ exists in the paraelectric phase, whose symmetry is different than in the ferroelectric phase.

## 3. Discussion

The theory of effects described above is still unsatisfactory. There are numerous papers on this subject ([1], [2], and references therein), in which, however, only one wave is taken into account. In our experiment, we had two beams going almost parallel [4], [5], so that they may be treated as one composed wave which – in the first approximation – may be put in the formula derived for one wave. The total incident wave is effectively a variable of the green light only (the red beam shifts the $0x$ scale by a constant value). The total outgoing wave consists of two waves, but we extract one of them which is relatively much more sensitive.

The most interesting result of our measurements is connected with a strong dependence of the bistable effect on the polarization of the incident green wave. First of all, the beam must be (linearly) polarized. Moreover, a very important role plays the angle of polarization. The loop monotonically diminishes with increasing this angle and disappears entirely above a certain value of this angle.

The decisive role in the observed behaviour plays the direction of the polarization vector of the green wave with regard to the surface of the $BaTiO_3$ plate. It influences directly the susceptibility tensor $\chi$ responsible for the phenomena considered. As is well known, the ferroelectric $BaTiO_3$ is an uniaxial crystal. In our experiment the crystal was oriented in such a way that the optical axis was perpendicular to the surface. The tensor $\chi$, connected with second order nonlinear effects, is a tensor of third order whose some components may be different from zero only when the electric vector $\boldsymbol{E}$ of the wave propagating inside the sample has a component along the optical axis [6]. On the other hand, in the paraelectric phase the crystal has a centre of symmetry. Therefore, all the components of the above tensor must vanish. The only possible effects must be thus linked to the fourth order susceptibility tensor. The observed bistabilities of the Stokes parameters are just examples of the third order nonlinear effects.

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## References

[1] GIBBS H. M., *Optical Bistability*, Academic Press, New York 1985.
[2] BOYD R., *Nonlinear Optics*, Academic Press, New York 1992.
[3] PETYKIEWICZ J., STROJEWSKI D., Opt. Appl. **19** (1989), 81.
[4] OKAMURA H., *et al.*, Opt. Commun. **99** (1993), 230.
[5] GRAEME W., *et al.*, Opt. Commun. **101** (1993), 60.
[6] CHMELA P., *Wprowadzenie do optyki nieliniowej* (in Polish), [Ed.] PWN, Warszawa 1987.