

system parameters and maximum output power. The results of the experiments are shown in the table and in Fig. 3. In addition, the beam divergence of the para-terphenyl laser was measured and found to be  $4 - 5'$ . It is interesting to note that even molecules of simple electronic structure, such as para-terphenyl or diphenylbutadiene, are capable of emitting radiation. Lasers using these molecules operate in accordance with the usual scheme of two singlet levels, broadening as a result of the system of vibrational and rotational sub-levels [1]. The experimental results indicate that lasing on the basis of the indicated mechanism can be effected not only in dyes, but in many organic compounds of other classes.

We have thus obtained for the first time uv generation from solutions of organic scintillators. Such lasers can find use in various investigations, particularly photochemical ones, when it is necessary to have a sufficiently strong monochromatic radiation in the 400 - 200 nm range. Heretofore, only several sources of emission lines were available in this range, namely at 353 (third harmonic of endodymium laser), 347 (second harmonic of ruby laser); 337 (molecular-nitrogen gas laser), and 265 nm (fourth harmonic of neodymium laser).

There is no doubt that the number of scintillators capable of lasing in the uv region can be increased manyfold, so that at least the spectral region from 300 to 400 nm will be fully covered by generation lines. It should be noted that even under non-optimal conditions the lasing threshold turned out to be low. This gives grounds for assuming that generation of uv radiation can be obtained from such compounds pumped with flash lamps. It is also important that many of the compounds of the types listed above, unlike the dyes used to obtain laser emission in the visible range, are much more stable against the action of ultraviolet radiation, oxidation, and other factors. Another advantage of these compounds is that they can be readily incorporated in plastic matrices, and therefore can be used as active elements of solid-state lasers.

We note also that these compounds are good energy acceptors, and can therefore be used for lasers in which the population inversion of the active levels is the result of energy transfer from other excited molecules (energy donors).

The authors are grateful to R. N. Nurmukhametov for supplying a number of compounds and for interest in the work.

[1] B.I. Stepanov, A. I. Rubinov, *Usp. Fiz. Nauk* 95, 45 (1968) [*Sov. Phys.-Usp.* 11, (1969)].

#### MICROWAVE-ABSORPTION FLUCTUATIONS AT PHASE TRANSITION IN BARIUM TITANATE

V. V. Bogatko, G. M. Guro, I. I. Ivanchik, and N. F. Kovtonyuk  
P. N. Lebedev Physics Institute, USSR Academy of Sciences  
Submitted 25 October 1968  
*ZhETF Pis. Red.* 9, No. 1, 19 - 23 (5 January 1969)

The notion that regions with anomalously high free-carrier concentration (on the order of  $10^{20} \text{ cm}^{-3}$ ) are located near the end faces of ferroelectric domains was advanced in [1 - 3]. To check on this notion, investigations were made of the light emission accompanying each act of  $\text{BaTiO}_3$  depolarization [4] and microwave absorption in barium titanate [5]. The experiments agree with the concept of screening of the spontaneous induction in ferroelectrics with

the notion of screening of the spontaneous induction in ferroelectrics with the aid of the free carriers [1 - 3]. In particular, it is shown in [5] that microwave absorption in  $\text{BaTiO}_3$  is particularly intense at the instant of polarization reversal, i.e., when the end surfaces of the domain grow through the crystal. This suggests that the microwave absorption should be particularly noticeable at the Curie point, where the domains vanish (or are produced) simultaneously with the free charges that screen them. The present paper is devoted to a verification of this hypothesis. We have observed that when the crystal goes through the Curie temperature intense fluctuations take place in the microwave absorption, and indicate the presence of strong dynamic processes at the instant of the phase transition.

The performance of the experiment was as follows. A single crystal of pure  $\text{BaTiO}_3$  (i.e., one containing no specially introduced impurities or defects)<sup>1)</sup>, measuring  $0.2 \times 3 \times 3$  mm and provided with silver electrodes, was placed in a 3-cm-band waveguide connected as described in [6] (see also [5]). The crystal was heated (or cooled) so that its temperature varied at a constant rate. The rate of temperature change was varied between 0.05 and  $4^\circ\text{C}/\text{sec}$ . We measured both the microwave absorbed by the crystal and the one reflected from it. Just as in [5], the reflected flux was smaller than the absorbed one by one order of magnitude. Both the reflected and transmitted fluxes were registered either with a pointer-type meter or with an oscilloscope. The absorption curve obtained with the meter is shown in Fig. 1. When this dependence is observed with a low-inertia instrument (S-19 oscilloscope) with a beam travel time 5 - 10 sec, essentially new features, not revealed by the meter, are observed near the Curie point. The form of the curve observed on the oscilloscope depends on the rate of change of the sample temperature. Low rates ( $dT/dt < 0.6^\circ\text{C}/\text{sec}$ ) and high rates ( $dT > 0.6^\circ\text{C}/\text{sec}$ ) of heating (cooling) can be distinctly separated. Let us describe first the observations at high rates of temperature change. Figure 2a shows an oscillogram of the microwave-transmission signal (a decrease of the signal is equivalent to an increase of absorption) at a heating rate  $dT/dt = 0.7^\circ\text{C}/\text{sec}$ . When the Curie temperature is approached from the low-temperature side, a smooth increase of the absorption is observed. The absorption increases jumpwise at the transition temperature, after which it immediately drops jumpwise to the level prevailing in the ferroelectric phase and then decreases smoothly with further increase of temperature. The

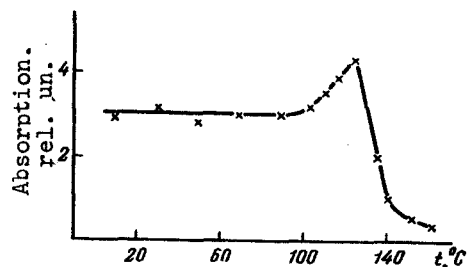


Fig. 1. Plot of microwave absorption vs. temperature, taken with a pointer meter.

transition in the opposite direction (upon cooling) is analogous. We now proceed to observations at low rates of heating (cooling). In this case the dependence of the transmission on the time (i.e., in final analysis, on the temperature, shown in Fig. 2a, becomes resolved and singularities that were blurred at high heating (cooling) rates become visible. Figure 2b shows a microwave oscillogram at a sample heating rate  $0.2^\circ\text{C}/\text{sec}$ . It reveals clearly the microwave-absorption fluctuations

<sup>1)</sup>The authors are grateful to E. V. Sinyakov (Dnepropetrovsk State University) for supplying the crystals.

occurring prior to the absorption jump. These fluctuations take place during a definite time interval, the duration of which does not change in different cycles of passage through the Curie temperature, and depends only on the rate of heating (cooling). The fluctuations themselves have a statistical character, i.e., the form and instant of each individual fluctuation do not repeat in various passages through the Curie point. To observe the fluctuations in greater detail, a fast oscilloscope sweep was used. Figure 2c shows the fluctuations in cooling at a rate  $dT/dt = 0.2^\circ\text{C}/\text{sec}$ , observed with the aid of the faster sweep. This oscillogram does not show the smooth transitions of absorption in the vicinity of the Curie point. The fast sweep was used to determine the minimum duration of the individual fluctuations, which turned out to be of the order of  $10^{-2}$  sec at  $dT/dt \sim 0.1^\circ\text{C}/\text{sec}$ . The maximum fluctuation duration was of the order of  $10^{-1}$  sec. The duration of the time interval in which the fluctuation occurs is inversely proportional to the rate of temperature change. In particular, by maintaining the temperature at which the fluctuations occur constant with the aid of smooth control, we observed a continuous mode of microwave absorption fluctuations lasting tens of minutes or more. As already indicated, although the fluctuations themselves have a statistical character, the temperature interval in which they occur is a constant characterizing the material. Figure 3 shows plots of  $1/t$ , where  $t$  is the time interval during which the fluctuation takes place, against the heating (cooling rate). It is seen from these plots that the temperature interval  $\Delta T$  in which the microwave absorption fluctuations take place in the vicinity of the phase transition, varies for the different employed crystals in the range  $0.06^\circ\text{C} \leq \Delta T \leq 0.3^\circ\text{C}$ . The value of  $\Delta T$  does not depend on the rate of temperature change. When a constant bias field (up to  $E \sim 10^4$  V/cm) is applied to the crystal, the transmission in the ferroelectric phase increases somewhat and the Curie point shifts, but no noticeable influence is observed on the magni-

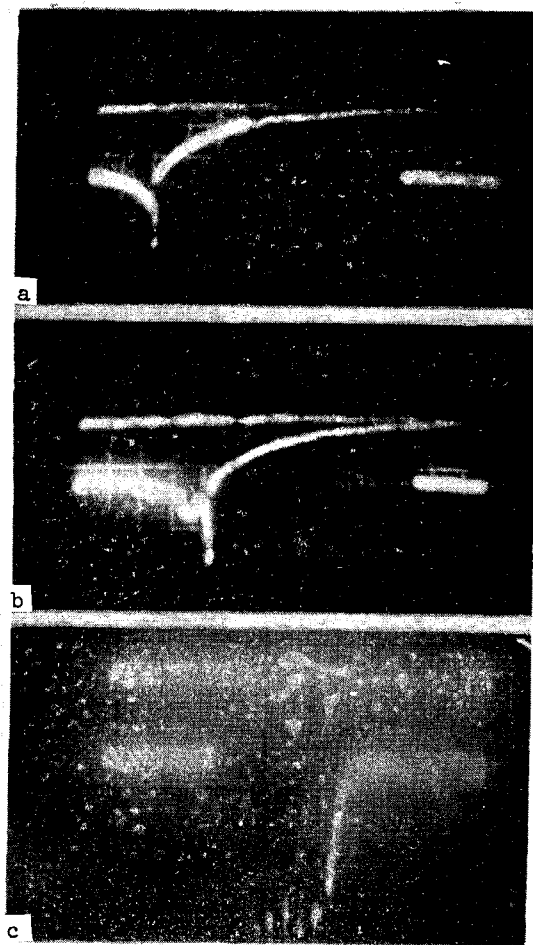


Fig. 2. Microwave transmission oscillograms near the Curie point: a - heating rate  $0.7^\circ\text{C}/\text{sec}$ , b - heating rate  $0.2^\circ\text{C}/\text{sec}$  (slow sweep), c - cooling rate  $0.2^\circ\text{C}/\text{sec}$  (fast sweep).

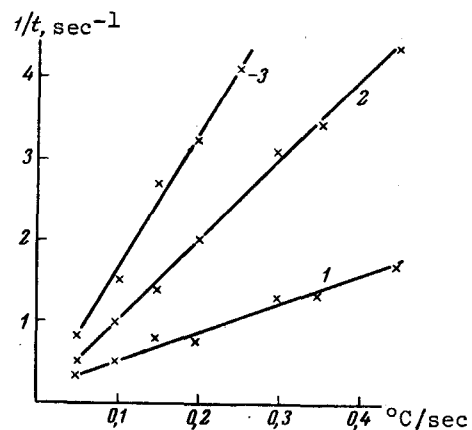


Fig. 3. Temperature dependence of the length of the fluctuation region, for three crystals, at  $\Delta T = 0.3^\circ\text{C}$  (1),  $0.1^\circ\text{C}$  (2),  $0.06^\circ\text{C}$

tude of the microwave absorption jumps. Nor is this effect influenced by application of an alternating current of frequency  $10^2 - 10^5$  Hz,  $E \sim 10^4$  V/cm.

- [1] G. M. Guro, I. I. Ivanchik, and N. F. Kovtonyuk, ZhETF Pis. Red. 5, 9 (1967) [JETP Lett. 5, 5 (1967)].
- [2] I. I. Ivanchik, Fiz. Tverd. Tela 3, 3731 (1961) [Sov. Phys.-Solid State 3, 2705 (1962)].
- [3] G. M. Guro, I. I. Ivanchuk, and N. F. Kovtonyuk, *ibid.* 10, 135 (1968) [10, 100 (1968)].
- [4] V. V. Bogatko, G. M. Guro, I. I. Ivanchik, and N. F. Kovtonyuk, *ibid.* 10, 2094 (1968) [10, (1969)].
- [5] V. V. Bogatko, G. M. Guro, I. I. Ivanchik, and N. F. Kovtonyuk, *ibid.*, in press.
- [6] T.S. Benedict and J. L. Durand, Phys. Rev. 109, 1958 (1958).

#### FOCUSING OF ION BEAMS BY A PLASMA LENS

V. V. Zhukov, A. I. Morozov, and G. Ya. Shchepkin  
 Submitted 4 November 1968  
 ZhETF Pis. Red. 9, No. 1, 24 - 27 (5 January 1969)

The idea of using axially-symmetrical space-charge shapes for the focusing of charged particles was advanced earlier (cf., e.g., [1, 2]). It was shown theoretically recently [3] that stationary axially-symmetrical plasma formation with closed electron drift in an external electromagnetic field act as focusing systems with respect to ion or plasma beams passing through them. This uncovers the possibility of developing a new type of corpuscular optics - plasma optics. Lenses of such optical systems - plasma lenses - on top of having a refractive power several orders of magnitude higher than that of an ordinary electrostatic or electromagnetic lens, should theoretically have no limitations with respect to the intensity and density of the focused beam, up to very high values of these quantities. Such a fortunate combination of the properties is due to the fact that in these systems the magnetic-induction lines are transformed into equipotentials of the focusing electric field within the volume of the plasma. The focal distance of a "short" lens of this type, made up of a stationary axially-symmetrical plasma in the vicinity of a metallic ring carrying a current  $I$  and having a potential  $+U$  relative to the ion source and collector, was later calculated [4] to be

$$f = \frac{\Phi}{2U} R \frac{1}{\theta} , \quad (1)$$

where  $R$  - radius of ring,  $\Phi$  - potential difference accelerating the ions, and  $\theta \sim 1$  depends on the geometric features of the system.

Putting  $\theta = 1$  and denoting by  $f_E$  and  $f_H$  respectively the focal distances of the purely electrostatic and electromagnetic lenses formed by the same ring, we can readily verify that  $f/f_E = 3.7 \times 10^{-2} U/\Phi$  and  $f/f_H = 2.8 \times 10^{-6} I^2/MU$  if the potentials are in volts, the current in amperes, and the mass  $M$  of the focused ions in atomic mass units. For example, for singly-charged argon ions ( $M = 40$ ) at  $\Phi = 10^4$  V,  $U = 10^3$  V, and  $I = 10^3$  A the focal distance of the plasma lens turns out to be smaller by two orders of magnitude than that of an electrostatic lens and four orders smaller than that of a magnetic lens, other conditions being equal.

Figure 1 shows schematically the setup for an experimental investigation of a plasma-lens model (1 - 5), where 1 - cross section of ring with current  $I$  and potential  $+U$ ; 2 - sections of thin metallic rings on which the potential is linearly distributed in the range  $0 - U$ ; 3, 4, 5