Cerenkov radiation from a propagating nonlinear polarization wave

D. A. Bagdasaryan, A. O. Makaryan, and P. S. Pogosyan
Erevan State University

(Submitted 7 April 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **37**, No. 10, 498–500 (20 May 1983)

Cerenkov radiation is obtained in the millimeter wavelength range from a nonlinear polarization wave propagating with superluminal velocity and its angular distribution is studied.

PACS numbers: 41.90. + e

Vavilov-Cerenkov radiation from a moving oscillator was studied by Frank in 1942.[1] Later, the possibility of Cerenkov radiation from an arbitrary wave was demonstrated.[2] A Cerenkov effect from a nonlinear polarization wave was first pointed out in Ref. 3 and a detailed analysis of this effect accompanying lasing at the difference frequency was performed in Ref. 4.

In spite of this, we are not aware of any reports of direct observations of Cerenkov radiation from a nonlinear polarization wave.

In this paper, we report the results of investigations of Cerenkov radiation from a nonlinear polarization wave in the millimeter wavelength region, arising due to a shift of the frequencies of a pulsed CO_2 laser in a GaAs crystal.

It is convenient to study Cerenkov radiation from a nonlinear polarization wave while generating the difference frequency, since the nonlinear polarization wave in almost all nonlinear crystals propagates with superluminal velocity (the index of refraction at the difference frequency is greater than at the frequencies of the exciting radiation). If we take into account that there exists an optimal radius of the exciting beams (the radius at which the efficiency of conversion of laser radiation is maximum), which for real situations is of the order of the wavelength at the difference frequency, then to obtain the effect indicated it is convenient to perform the investigations in the microwave region. In addition, quite sensitive receiving apparatus with fast response is available for this region. Thus, for example, for Gaussian exciting beams the effective radius is determined from the relation

$$r_0 = \frac{\lambda}{2\pi n \sin\theta_0} \tag{1}$$

where λ is the wavelength of the radiation, and θ_0 is the Cerenkov angle ($\cos\theta_0 = n_0/n$, and n_0 and n are the refractive indices of the crystal for the exciting and the excited radiation, respectively). An estimate using Eq. (1) for a GaAs crystal gives a beam radius $r_0 = 0.23\lambda$, which is easily realized experimentally at millimeter wavelengths.

The block diagram of the experimental setup is shown in Fig. 1.

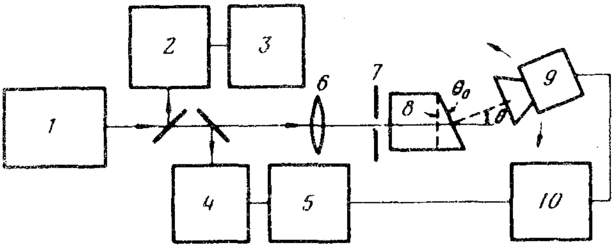

FIG.1. Block diagram of experimental setup. 1—Pulsed TEA CO_2 laser; 2—drag detector; 3—S7-10A oscillograph; 4—monochromator; 5—Ge:Au detector; 6—lens ($F = 30$ cm); 7—diaphragm; 8—GaAs crystal; 9—horn with detecting head; 10—S8-2 oscillograph.

The experiments were performed at 54.3 GHz ($\lambda = 5.6$ mm), which corresponds to the difference in the frequencies of two neighboring rotational lines, $P(20)$ and $P(22)$, of the 00°1–10°0 transition of the CO_2 molecule.

The laser was tuned to two neighboring lines by selecting the partial pressure of the mixture (CO_2:N_2:He = 1:3:2) and the parameters of the resonator. Part of the laser radiation is directed at a drag detector connected to a S7-10A oscillograph, with the help of which the shape and temporal overlap of the exciting beams was studied. The pulse duration was ~ 80 ns. The energy of the lasers, which was measured with the help of IMO-2, was ~ 0.8 J. We used special horn antennas to measure the angular distribution of the Cerenkov radiation and we used a D407 diode to detect the microwave radiation.

A high-resistance GaAs crystal ($\rho > 10^8$ Ω cm) was oriented in such a way that the intensity vector of the electric fields of the exciting beams was parallel to the [111] crystallographic direction.

It is well known that the effective nonlinear interaction length is limited by losses in the crystal (it is of the order of the inverse absorption coefficient). For this reason, the coefficient of absorption α of the specimen was measured using a standard waveguide method[5] and at a wavelength of 5.6 mm, it was 1.2 cm^{-1}. We used crystals with a length $L = 1/\alpha = 5;6$ cm. To extract the Cerenkov radiation, the output face of the crystal was cut at an angle $90° - \theta_0 = 68°$.

The measurements showed that for a laser beam radius $r = r_0 = 1.3$ mm, the radiation power at the difference frequency is confined to the Cerenkov cone and the angular width (at half-height) is $\sim 10°$. The maximum power in this case is ~ 30 mW, which is almost an order of magnitude smaller than the theoretical estimate in Ref. 4, if the magnitude of the nonlinear susceptibility of GaAs is assumed to be $\chi = 3 \times 10^{-6}$ CGSE.[6] This disagreement could be due to the error in the value of χ, as well as to the deviation of the shape of the laser beams from a Gaussian shape.

Numerical calculations, using the angular distribution of the radiation at the difference frequency from the results obtained in Ref. 4, show that it has a lobe structure, which we did not record (see Fig. 2).

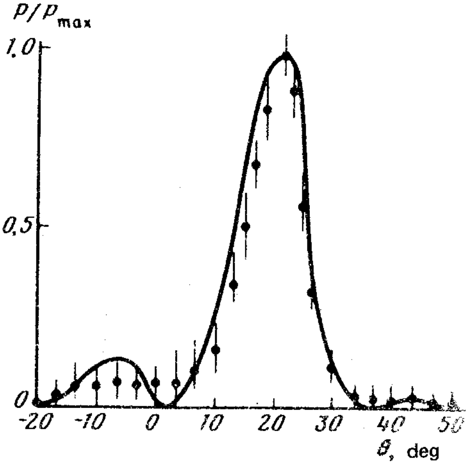

FIG. 2. Angular distribution of radiation power at the difference frequency. The solid curve was calculated with allowance for the refraction of the radiation at the exit from the crystal. The dots show the experimental points.

Further, more detailed investigations of this phenomenon could have many applications, such as in determining the nonlinear parameters of crystals and the characteristics of the lasers themselves, as well as obtaining new types of millimeter sources.

We thank M. L. Ter-Mikaelyan for valuable discussions.

[1] I. M. Frank, Izv. Akad. Nauk SSSR, Ser. Fiz. **6**, 3 (1942).
[2] V. L. Ginzburg, Usp. Fiz. Nauk **69**, 537 (1959) [Sov. Phys. Usp **2**, 874 (1959)].
[3] G. A. Askar'yan Zh. Eksp. Teor. Fiz. **42**, 1360 (1962) [Sov. Phys. JETP **15**, 943 (1962); *ibid.* **45**, 643 (1963) [*ibid.* **18**, 441 (1964)].
[4] S. P. Abdullin, G. A. Lyakhov, O. V. Rudenko, and A. S. Chirkin, Zh. Eksp. Teor. Fiz. **66**, 1295 (1974) [Sov. Phys. JETP **39**, 633 (1974).
[5] A. A. Brandt, Issledovanie diélektrikov na SVCh (Investigation of Insulators at Microwave Frequencies), Moscow, 1963.
[6] T. Y. Chang, N. Van Tran, and C. K. N. Patel, Appl. Phys. Lett. **10**, 357 (1968).

Translated by M. E. Alferieff
Edited by S. J. Amoretty