since $\mathcal{E}_d$ exceeds the gain saturation energy $\mathcal{E}_s$ necessary to compress the pulse. For ruby at 300°K, $\mathcal{E}_d \simeq 10$ J/cm^2 [4] and $\mathcal{E}_s \simeq 4$ J/cm^2. This ratio is especially favorable if the ruby crystals are cooled, when $\mathcal{E}_s < 1$ J/cm^2.

5. To obtain extremely short pulses of light, effective two-component media are those in which the absorbing component has a saturation energy much lower and a homogeneous line width much larger than the amplifying medium. A light pulse propagating in such a medium can be compressed to the limiting duration determined by the reciprocal line width of the amplifying component. The duration of the leading front is determined by the absorbing component and can be much shorter than the duration of the entire pulse. When such a "limiting" pulse passes through the medium, the absorbing component is bleached, and the atoms of the amplifying component are inverted.

[1] N. G. Basov, R. V. Ambartsumyan, V. S. Zuev, P. G. Kryukov, and V. S. Letokhov, JETP 50, 23 (1966), Soviet Phys. JETP 23, 16 (1966).

[2] V. S. Letokhov and A. F. Suchkov, JETP 50, 1148 (1966), Soviet Phys. JETP 23, in press.

[3] R. V. Ambartsumyan, N. G. Basov, V. S. Zuev, P. G. Kryukov, V. S. Letokhov, and O. B. Shtaberov, JETP 51, No. 2(8), 1966, Soviet Phys. JETP 24, in press.

[4] P. V. Avizonis and T. Farrington, Appl. Phys. Lett. 7, 205 (1965).

GENERATION OF COHERENT RADIATION IN THE INFRARED BAND BY NONLINEAR-OPTICS METHODS

S. A. Akhmanov, G. V. Venkin, B. V. Zubov, and R. V. Khokhlov
Physics Department, Moscow State University

Submitted 3 May 1966
ZhETF Pis'ma 4, No. 1, 22-26, 1 July 1966

We report in this letter experimental results offering evidence that sufficiently intense sources of coherent infrared radiation, at least in the 2 - 5 μ range, can be produced by using the effect of optical mixing in nonlinear media. We have realized in our experiments for the first time effective synchronous mixing of radiation from a Q-switched ruby laser ($\lambda_l = 6943$ Å) with radiation of the first Stokes component of stimulated Raman scattering (SRS) in cyclohexane ($\lambda_c = 8657$ Å) and n-heptane ($\lambda_c = 8677$ Å) in an $LiNbO_3$ crystal. This produced at the output of the nonlinear crystal radiation pulses with wavelength $\lambda_p = 3.5$ μ ($\nu_p = 2853$ cm^{-1}) and $\lambda_p = 3.47$ μ ($\nu_p = 2878$ cm^{-1}) respectively, with power not lower than 1 - 10 W. We recall that mixing with an output signal in the infrared band entails appreciable difficulties. Most important among them are: need for choosing a crystal that supports the presence of accumulating interactions (synchronism directions), difficulty of recording short pulses of infrared radiation, and much more stringent demands with regards to spatial coherence of the interacting beams (compared with the optical band) (see, e.g., [1]).

To overcome the foregoing difficulties, we chose as the nonlinear crystal $LiNbO_3$ [2], which is transparent in the 0.4 - 5 μ band and has, as shown by calculation, sufficient birefringence for realization of accumulating interactions in its optical transparency range [1)].

The mixing of ruby-laser emission with the Stokes SRS emission stimulated by it in organic liquids ensured a high degree of spatial coherence of the beams and automatic temporal synchronization.

Let us discuss first the conditions for the realization of accumulating nonlinear interactions in the $LiNbO_3$ crystal. Mixing can give rise here to accumulating interactions of two types, for which the synchronism conditions are:

$$\vec{K}_{po} = \vec{K}^{e}_{l} - \vec{K}_{co}, \tag{1}$$

$$\vec{K}^{e}_{p} = \vec{K}^{e}_{l} - \vec{K}_{co}. \tag{2}$$

Here $\vec{K}_i$ are the wave vectors of the wave propagating in the crystal; the indices o and e pertain to the ordinary and extraordinary waves. The amplitudes of the nonlinear polarization waves in $LiNbO_3$, which excite the ordinary wave at a frequency ω_p and the extraordinary wave at the frequency ω_p, are:

$$P_o(\omega_p) = E_l E^*_c[\chi_{131} \sin\theta + \chi_{222} \cos\theta \cos 3\varphi], \tag{3}$$

$$P_e(\omega_p) = E_l E^*_c[-\chi_{222} \cos^2\theta \sin 3\varphi]. \tag{4}$$

Here θ is the angle between the direction of the incident beam and the optical axis of the crystal, φ the angle between the plane of incidence and the plane of mirror symmetry of the crystal, and χ_{131} and χ_{222} the spectral components of the nonlinear polarizability tensor. According to [2], the theoretical synchronization angles are θ_s = 46°04' and 45°30' for interaction of type (1) using n-heptane and cyclohexane, respectively, and θ_s = 51°37' and 50°51' for interaction of type (2).

We used in the experiments lithium niobate samples measuring 6.5 x 6.5 x 8.0 mm, cut at the following synchronism angles given by (3) and (4): $\theta = 45° \pm 2°$, $\varphi = 0° \pm 2°$ and $\theta = 51° \pm 2°$, $\varphi = 90° \pm 2°$. A block diagram of the experimental setup is shown in Fig. 1. The radiation from the Q-switched ruby laser was focused by lens L_1 (f = 7.0 cm) in a cuvette (l = 10 cm) and excited SRS at the Stokes component in cyclohexane and n-heptane. The radiation from the cuvette was focused by lens L_2 (F = 10 cm) on the $LiNbO_3$ crystal; the power density in the crystal was $S_l \simeq S_c \simeq 1.0$ MW/cm^2. The radiation from the crystal was recorded with a germanium photoresistor IPR) doped with gold, operating at liquid-nitrogen temperature and located at the exit from an infrared monochromator. The power of the output radiation was not lower than 1 - 10 W. Figure 2 shows an oscillogram of the difference-frequency pulse. We paid particular attention to the experimental confirmation of the deduction that accumulating (synchronous) nonlinear interaction has been realized. This is borne out by the following: (i) we checked with the aid of a germanium plate mounted at the Brewster angle that the polarization of the infrared radiation is correctly

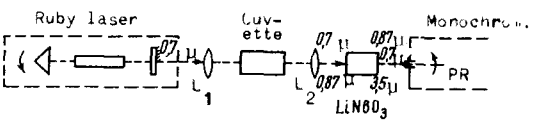

Fig. 1. Block diagram of experimental setup. L_1 - lens (f = 7 cm), L_2 - lens (f = 10 cm), PR - photoresistor.

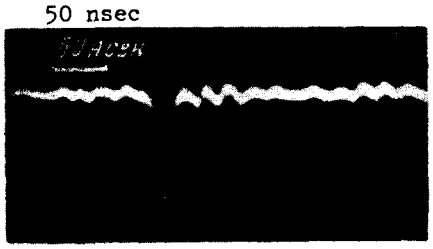

Fig. 2. Oscillogram of difference-frequency pulse

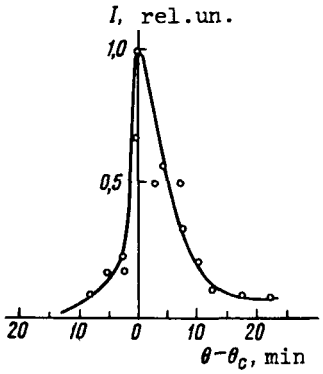

Fig. 3. Dependence of the power radiated at the difference frequency on the orientation of the $LiNbO_3$ crystal relative to the laser beam

predicted by formulas (1) and (2); (ii) the most convincing proof of the synchronous character of the observed interaction is provided by measurement of the dependence of the intensity of the output signal on the orientation of the crystal relative to the laser beam (see Fig. 3). We see that a deviation of 6' from the synchronism direction causes the output power to decrease by one-half.

Theoretical estimates of the power at the difference frequency, attainable in these experiments, yield a value ~500 W. Differences between this value and experiment can be attributed to the multidomain structure of the $LiNbO_3$ crystal used by us. In this case the nonlinear parameters χ_{131} and χ_{222} experience random spatial modulation, thus reducing the efficiency of the nonlinear interaction. The results allow us to count on covering with the aid of the described system at least the 2 - 5 μ band at an output power not lower than 5×10^2 W. Besides using the SRS lines, it is quite promising to use for the mixed oscillations the spectral lines obtained from a tunable parametric light generator (cf., e.g., the review [5]). The use of the output signal of this generator would permit, in our opinion, to operate in the 100 - 150 cm^{-1} region with the aid of the system described by Zernike and Berman [4]. We note, finally, that in our system, the introduction of mirrors that reflect at frequencies ω_c and ω_p can lead to self-excitation of oscillations at these frequencies, if the power density at the frequency ω_p is sufficiently high.

We are grateful to A. S. Bebchuk and Yu. I. Solov'eva for supplying the crystals, V. I. Pchelkin for help with the experiment, and A. G. Ershov and V. V. Fadeev for a discussion of the results.

[1] I. Ducuing and N. Bloembergen, Phys. Rev. 133A, 1493 (1964).
[2] G. Boyd, R. Miller, K. Nassau, W. Bond, and A. Savage, Appl. Phys. Lett. 5, 234 (1964).
[3] M. Martin, E. Thomas, and I. Wright, Phys. Lett. 15, 136 (1965).
[4] F. Zernike and P. Berman, Phys. Rev. Lett. 15, 999 (1965).
[5] S. A. Akhmanov and R. V. Khokhlov, UFN 88, 439 (1966), Soviet Phys. Uspekhi 9, in press.

[1] The unsuitability of ZnS and CdS crystals for use as optical mixers is apparently the main reason for the negative results obtained in the experiment described in [3]. We note

that our data agree with the results cited there.

MAGNETORESISTANCE OF BISMUTH IN FIELDS UP TO 450 kOe AT HELIUM TEMPERATURES

N. B. Brandt, E. A. Svistova, and G. Kh. Tabieva
Physics Department, Moscow State University
Submitted 3 May 1966
ZhETF Pis'ma 4, No. 1, 27-32, 1 July 1966

1. The study of galvanomagnetic phenomena in metals in the ultraquantum region, when the distances between the Landau levels become comparable and exceed the Fermi energy, affords a unique opportunity of investigating the structure of the energy spectrum of metals in a sufficiently broad energy interval near the Fermi boundary [1,2]. The structure of the spectrum changes in the ultraquantum region as a result of the change in the band boundaries, the Fermi energy in the bands, the carrier density, and the carrier distribution among the separate equal-energy surfaces. The character of this change is determined directly by the carrier dispersion, and therefore its investigation yields valuable information on the character of the dispersion law.

2. Effects connected with the transition into the ultraquantum region are easiest to observe in metals with low carrier density. In this paper we report results of an investigation of the electric resistance of single-crystal samples of bismuth in a transverse magnetic field H of intensity up to 450 kOe at liquid-helium temperature.

The magnetoresistance of bismuth in fields up to 300 Oe was first investigated in [3] at 77°K and it was observed that in strong fields the dependence of ρ on H is close to linear. As far as we know, the fields in which the electric resistance of bismuth was investigated at helium temperatures did not exceed 100 kOe [4,5].

3. To obtain the magnetic field we used a pulse installation with a period of 316 μsec. The main difficulty in the investigation of galvanomagnetic effects in pure metals at low temperatures by means of short-period magnetic-field pulses is that as the field is increased the small skin depth causes the samples to be destroyed by the interaction between the eddy currents and the field. This difficulty was eliminated by applying a primary constant magnetic field to increase the resistance of the sample by the required number of times.

Samples of different shapes (parallelepipeds, cylinders) and sizes (from 1 x 1 x 3.5 mm to 0.2 x 0.4 x 2.5 mm) were made of bismuth of two grades. Bi_1 with $\rho_{300}/\rho_{4.2} = 300 - 400$ and Bi_2 with $\rho_{300}/\rho_{4.2} = 150$. The nominal purity of both grades was higher than 99.9999%. The measurements were made on a large number of samples at all possible orientations of the magnetic field and of the current relative to the crystallographic axes. As a result of a thorough investigation of the influence of the geometry of the samples, the arrangement of the electrodes, the influence of the measuring-current strength, which determines the overheating of the sample during the pulse ("thermal shock"), and the method of fastening the sample, conditions were chosen under which the influence of the parasitic effects (especially those in [6]) could be neglected in practice. All the results given below are perfectly reversible and