beam. This method has been proposed here primarily as a means of studying the autocorrelation function of the frequency fluctuations of a laser beam in an attempt to discriminate between external instabilities of the optical cavity and the internal noise process driving the oscillations. There are at present no other practical methods for making such measurement, and hence, the method proposed here may be of considerable importance. Attempts to demonstrate this method experimentally are now in progress.

The method proposed can also be used for other measurements. For example, it can be used to study the correlation between two different parts of any laser beam. These parts can even have different frequencies (for example, two modes of a laser), or can arise from propagation through different regions of a turbulent propagating medium. For some applications the method can be modified by inserting an integrator between each discriminator and the multiplier, so as to analyze phase and not frequency fluctuations.

Acknowledgment

We are grateful to Prof. A. E. Siegman for helpful discussions in the development of this work.

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2A1(b)—Opening Remarks: Fourth International Quantum Electronics Conference

N. G. BASOV

IT IS A WELCOME fact in the tradition of quantum electronics conferences that we have always paid more attention to the consideration of ideas rather than to the analysis of completed research. The first conference considered all types of lasers (based on luminescent crystals, gases, and semiconductors), the second paid attention to Q-switched and semiconductor lasers, while the third featured the problems of coherence, nonlinear optics, and interaction of radiation with matter. The conference on physical research in the field of quantum electronics that took place in Puerto Rico was also a good example of this tradition.

This may be the result of a general rule characterizing new sciences which have not yet been burdened by heavy industrial production problems, whose limits have not yet been clearly drawn, and in which ideas are not merely means of overcoming creative or industrial bottlenecks, but are the guidelines for the entire direction of development of considerable promise for the future.

In the spirit of this tradition, without wasting time on general remarks, I will try to describe briefly those ideas which are being given primary attention in my laboratory at the Lebedev Physical Institute. Some of these areas were not included in the conference agenda because of limitations and the fact that not all those who wanted to could come to this conference owing to the great distance between Phoenix and Moscow. The work I want to discuss mainly concerns the Laboratory of Quantum Radiophysics: however, it is also partially connected with other laboratories of our Institute. A portion of our work is also related to the investigation of the possibility of utilizing the methods of quantum electronics in order to increase the accuracy in meterology.

Our laboratory has suggested a method of resoving the hyperfine structure of the ammonia line using two resonators in series by means of modulating the resonator spacing. Such a modulation should cause a phase shift in the second resonator if the frequency of the first does not coincide with the frequency of the spectral line. According to computations (see Fig. 1) measurements taken at various saturation levels of the spectral line may resolve the hyperfine structure of the line with an accuracy

$$\frac{\Delta\nu}{\nu} \sim 10^{-10} - 10^{-11}.$$

We are now conducting research on the design of optical frequency standards.

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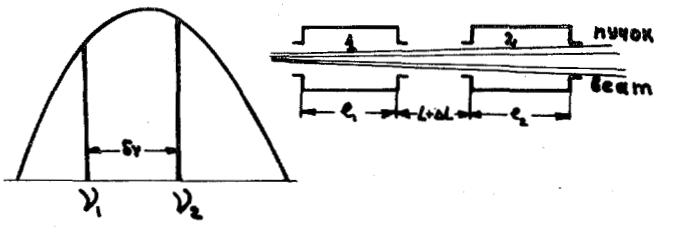

$$\delta\nu = \frac{2\bar{b}}{\pi\Delta L\left|\frac{3l_2 + 6L}{l_1}\right|} \cdot\left(T + \frac{\tau_2}{2} + \frac{\tau_1}{2}\right)\sqrt{\dot{\chi}^2}\sqrt{\frac{8\beta}{\theta(\Omega^2 + \beta^2)}} = \approx 10w$$

Fig. 1.

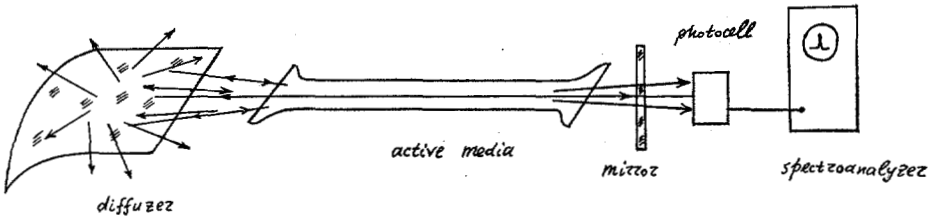

Fig. 2.

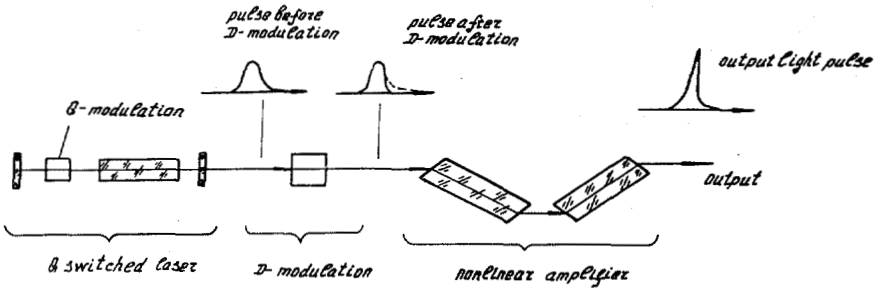

Fig. 3.

Our laboratory has created a laser which cannot be reported on within the scope of reports assigned to us by this conference. It is a laser with a nonresonant feedback in which the mirrors are replaced by scattering elements based on volumetric or surface scattering effects [1]. (See Fig. 2.) The spectral line thus becomes the only resonance element in such a laser. As a result, such an instrument has a very high monochromaticity of emission and may serve as a good frequency standard in the optical range. At the present time ruby and gaseous lasers of this type have been put into operation. These lasers are presently undergoing quantitative research. It should be noted that according to our investigations the emission from such a device, while marked by a high monochromaticity, does not have spatial coherence.

We are at this time investigating the possibility of creating semiconductor amplifying media characterized by noticeable gain over distances of the order of emission wavelength. In such media one can expect new interesting effects due to changes in emission spectrum, emission modes, and nonlinear optical properties.

Let me say a few words on the limiting emission powers obtainable from lasers. During session 5A we report on a double-modulation laser, that is, a laser incorporating both Q-switching and modulation of pulse length. Based on the nonlinear amplification effect (see Fig. 3), such lasers may yield very short pulses with tremendous power limited only by the radiation resistance of the material [2]. The achieved pulse length does not exceed 2 ns with an energy of about 10 J, offering favorable opportunities for the investigation of new effects connected with the interaction of radiation with matter. In particular, we are investigating the problem of high-temperature heating of plasma [3] and of the strength of crystals in strong light fields of short duration. We are also investigating the possibility of shortening the length of the light pulse in propagation in nonlinear transparent media, that is, "self-shortening" of the pulse.

What are the possibilities for a further increase in power? A study of the strength of ruby carried out in the Luminescence Laboratory by focusing an emission pulse with a length of 10^{-8} seconds in various regions

shows that the limiting strength of ruby with respect to the radiation amounts to 10^{11} W/cm^2; that means that it is considerably higher than the intensity reached at this time in large volumes of ruby [4].

Our laboratory is carrying out many investigations in laser theory [5]. The results of our work on the theory of spiking in lasers are contained in particular in the proceedings of the Puerto Rico Conference [6]. At this time we are conducting an experimental verification of the theory using superconducting and double-mode resonators in a maser based on an ammonia molecule beam. This theory served as a basis for the suggestion of a number of methods for obtaining quasi-periodic pulses in various types of lasers with a length from 10^{-10} to 10^{-11} seconds.

The above efforts are closely related to work on the use of semiconductor diode lasers, where we have experimentally proven the possibility of activating lasers by varying current in a time interval not over 5×10^{-11} seconds or by light pulses [7].

In the laboratory we pay considerable attention to the investigation of semiconductor lasers with electron and optical pumping [8], [9].

The efficiency of light conversion with optical pumping today exceeds 50 percent, while power is about 200 kW and power density amounts to about 10 to 20 MW/cm^2.

Two-photon absorption of light has been investigated in detail in a number of semiconductors and the process has been successfully used to obtain laser generation [10].

Many attempts are being made today to move toward the shortwave range. Electron beam pumping succeeded in producing recombination radiation (wavelength of 3300 Å) in zinc sulfide crystals and laser generation (wavelength of 4300 Å) in zinc selenide.

Attempts are being made to use noble gases at low temperatures as the working media to obtain emission in the region of the far vacuum ultraviolet. According to preliminary estimates, in spite of the broad linewidths due mainly to exchanger interaction, one can expect here a narrow emission line similar to the case of semiconductors, since the collective excitation of atoms at low temperature would be concentrated near the edge of the line.

In conclusion, I would like to say a few words about the parametric oscillator which has been built at Moscow University [11]. The creation of tunable parametric oscillators is a major achievement of quantum electronics of the last few years. Such oscillators will, for example, allow for a fuller utilization of the properties of resonant emission in its interaction with matter. A special report by Giordmaine and Miller will be devoted to the subject at this session (2A).

The schematic of such an oscillator based on KDP crystals is shown in Fig. 4. Variation of the angle between the direction of light propagation and the optical crystal axis, that is, the rotation of the crystal, will change its dispersion characteristics and, consequently, the output frequencies ω_1 and ω_2. The dispersive properties of the

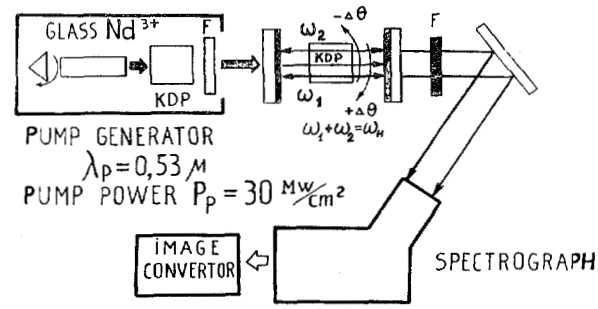

Fig. 4.

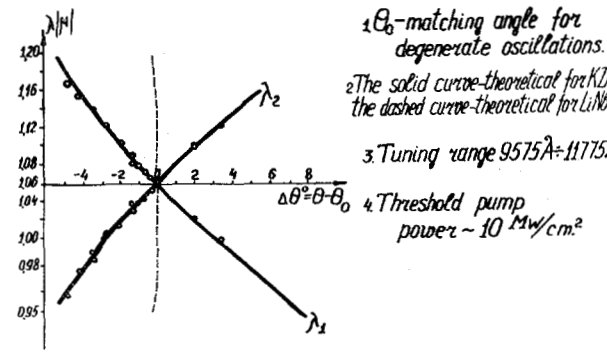

Fig. 5.

KDP crystal make it possible to obtain a linear relationship between frequency and the turning angle of the crystal. The parameters of the oscillator and the experimental plot of the frequency characteristic are given in Fig. 5. We shall note that in the case of lithium niobate, frequency as a function of the turning angle has a square root form making it practically impossible to achieve smooth frequency tuning.

I would like to take this opportunity on behalf of the Soviet delegation to thank the Steering Committee of the Conference for the fine organization of the Conference and for the very apt selection of papers.

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3C3—Geometrical Model and Experimental Verification of Two-Photon Absorption in Organic Dye Solutions

F. P. SCHÄFER AND W. SCHMIDT

***Abstract*—Two-photon absorption in solutions of organic dyes has been quantitatively measured in a wide range of wavelengths, extinction coefficients, and concentrations. The measurements are shown to be in good agreement with the simple assumption that the probability of double hits of photons on the area extended by the π-electron cloud of a molecule determines the rate of two-photon absorption.**

THERE HAVE been several papers during the last few years concerned with two-photon absorption experiments and their theoretical implications [1]. While all of the theoretical papers tried to explain the experiments on a quantum mechanical basis, the simple geometrical model we use seems not to have been considered. The experimental papers have either been concerned with two-photon absorption in crystals or do not give all the necessary information for a complete comparison with any theory, whereas we have used solutions of organic dyes for our experiments, which are particularly well suited for quantitative evaluation.

To derive the absorption of a laser beam passing through a cell with dye solution, we assume a photon flux n at wavelength λ_0 and a dye-molecule concentration m, the molecules showing no absorption at λ_0, yet a strong absorption band near $\lambda_0/2$. The maximum one-photon absorption cross section (for parallel orientation of the transition moment of the molecule and the electric vector of the exciting light beam) σ_{max} exhibited at the peak of the $\lambda_0/2$-absorption band, as determined from the molar decadic extinction coefficient $\epsilon(\lambda)$, is very nearly equal to the area of the molecule over which its π-electron cloud extends [2]. This π-electron cloud is disturbed when a photon is passing through it, the transient lasting in a first approximation for the time of flight of the photon through the electron cloud, i.e., for a time w/c, where c is the velocity of light and w is the distance over which the electron cloud is extended normal to the molecular plane. Then we have for the number m^* of molecules which are in this transition state,

$$m^* = \frac{m}{3}\sigma_{max} n \frac{w}{c}. \quad (1)$$

(The factor $\frac{1}{3}$ takes care of the statistical orientation of the molecules relative to the direction of the light beam.) Now we postulate that each of these transient molecules that is hit by a second photon absorbs both photons just like one photon of wavelength $\lambda_0/2$. Then the at-

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