

sult of the interaction of the superconducting vortices with the surface of the superconductor.

6. Modern materials capable of carrying large currents are obtained as a result of complicated mechanical working and heat treatment. This produces in them a layered-filamentary microstructure. The separation of the normal-phase particles usually begins on the boundaries of the fibers. Therefore the film considered in Sec. 5 can be regarded as a certain idealization of such a fiber. This uncovers the possibility of combining the "sponge" and "pinning" models. It is possible that the peak effect in the film (see the figure) explains the peak effect observed in many rigid superconductors.

¹V. L. Ginzburg and L. D. Landau, *Zh. Eksp. Teor. Fiz.* 20, 1064 (1950).

²N. E. Alekseevskii, I. Glasnik, and A. V. Dubrovin, *ibid.* 54, 84 (1968) [*Sov. Phys.-JETP* 27, 47 (1968)].

³V. V. Shmidt, *ibid.* 45, 1992 (1963) and 47, 387 (1964) [18, 1368 (1964) and 20, 258 (1965)].

⁴V. V. Shmidt, in: "Metallovedenie i metallofizika sverkhprovodnikov (Metallurgy and Metal Physics of Superconductors), Nauka, 1965, p. 17.

⁵P. W. Anderson, *Phys. Rev. Lett.* 9, 309 (1962).

⁶V. V. Shmidt, *ZhETF Pis. Red.* 9, 494 (1969) [*JETP Lett.* 9, 301 (1969)].

⁷V. V. Shmidt, *Zh. Eksp. Teor. Fiz.* 57, 2095 (1969) [*Sov. Phys.-JETP* 30, 1137 (1970)].

V. L. Tal'roze. Chemical Lasers.

The present status of research and the results attained in the field of chemical lasers, compared with other existing types of lasers, are quite modest, although the very idea of chemical lasers is almost as old as the lasers in general. Non-equilibrium excitation in the associated chemiluminescence of the products of a large number of chemical reactions have been known for a long time, and have been investigated in sufficient detail. On the other hand, the formation of an inverted population of vibrational levels was apparently first observed by Polyani in 1961 in the HCl molecule produced in the reaction between atomic hydrogen and the chlorine molecule. It was this reaction which led, in final analysis, to the development of the first chemical laser in 1965 by Casper and Pimentel.

What attracts researchers to chemical lasers is apparently the following: (1) The large energy reserve per unit volume and weight of the reacting substance. (2) The practically unlimited volume in which the process of such an energy release can be organized. (3) The possibility of direct transformation of chemical energy into an energetically perfect optical form of energy and the production on this basis of laser power systems, which so far, of course, are still in the fantasy stage.

In the USSR, papers on chemical lasers were published by four groups of scientists: N. G. Basov, A. N. Oraevskii, and co-workers (Physics Institute, USSR Academy of Sciences), Dolgov-Savel'ev and co-workers (Nuclear Physics Institute, Siberian Division

of the USSR Academy of Sciences), R. V. Khokhlov and co-workers (Moscow State University), and the author's own group at the Institute of Chemical Physics of the USSR Academy of Sciences. So far, all the actually operating chemical lasers are based on chemical reactions in which they are elementary acts that lead to the formation of vibrationally-excited molecules HCl, DCl, HF, and DF. In 1963, the author presented the principles of the kinetic theory of the chemical laser. One of the conclusions of this theory was the advantage of chain and especially branched-chain chemical reactions as the working process in chemical lasers. There are at least two such advantages: the possibility of transferring the system from a relatively stable state into a state of rapid reaction to small changes of temperature or pressures, namely the transfer of the system to the ignition region, and the spontaneous increase of the reaction rate in this region as a result of branching of the chain to rate values at which the creation of inversion overtakes the relaxation to such an extent that generation with considerable efficiency becomes possible. The first generation with the aid of a branched-chain chemical reaction was realized in 1968 by the author together with G. K. Vasil'ev and O. M. Batovskii. The working mixture was the hitherto unused $H_2 + F_2 + O_2$ mixture. The branched-chain character of the chemical reaction in this mixture was discovered earlier by N. N. Semenov, A. E. Shilov, and co-workers at the Institute of Chemical Physics. The branching itself is here energetic ($HF^* + F_2 \rightarrow HF + 2F$). With the aid of a low-power and short electric discharge it was possible to transfer the mixture to the region of self ignition both through the first and through the second limit, and short generation pulses were obtained, lasting several microseconds, with a peak power on the order of 10 kW and a chemical efficiency up to 2%.

The constants of the rates of all the elementary acts of the reaction were measured independently, and this made it possible to construct a semiquantitative theory of such a laser; the conclusions of such a theory are in satisfactory agreement with experiment.

The published data on chemiluminescence on electronic transitions, on the basis of which no one has yet succeeded in developing a chemical laser, are analyzed in the paper. In particular, strongly luminescing reactions in liquids are considered, particularly reactions of the type that determine the luminescence of biological objects (e.g., oxidation of luciferin, where the light yield reaches 88 photons per 100 reacting molecules). The main problem, for which a solution is still unknown, is that of "rapid" realization of these reactions.

V. V. Fadeev. Ultraviolet Lasers Using Organic Scintillators

1. One of the important problems of quantum electronics is to obtain powerful radiation in the UV band and to ultimately cover the entire band. To solve this problem it is necessary to produce in the UV band sources whose frequency can be continuously varied. One of the promising methods is the method of converting the frequencies of the available sources (e.g.,

ultraviolet harmonics of the emission of ruby and neodymium lasers) in organic compounds and generation with such compounds.

2. This method was used to solve practically completely the problem of filling the visible band. The active processes used in this case are organic dyes^[1]. In the UV region, however, the use of dyes is impossible, since organic compounds suitable for the generation in this band should have the following basic properties:

- a) intense absorption in the UV band (the extinction coefficient should amount to tens of thousands of $l/\text{mole-cm}$);
- b) large fluorescence quantum yield in the UV band;
- c) high stability to the action of powerful UV radiation.

All these properties are possessed by organic compounds used traditionally to record nuclear radiation and electron streams, namely scintillators. These properties of organic scintillators are in agreement with modern theory of the electronic structure of molecules. The molecules of aromatic and heteroaromatic compounds, such as scintillators, are characterized by the presence of a well conjugated π system. The spectral properties of such molecules (at least up to the vacuum ultraviolet) are determined exclusively by $\pi-\pi^*$ transitions, which explains fully the properties listed above. This distinguishes them significantly from molecules of most dyes, in which transitions of other types are possible together with $\pi-\pi^*$ transitions (e.g., $n-\pi^*$).

3. The first scintillator tested by us for the purpose of obtaining generation was para-terphenyl dissolved in cyclohexane^[2,3]. Excitation of the fourth harmonic of a neodymium laser ($\lambda_p = 265 \text{ nm}$) yielded generation at a wavelength $\lambda = 340 \text{ nm}$.

4. By now, generation was obtained with a large number of scintillators. We used for the pumping the fourth harmonic of a neodymium laser^[2-4], the third harmonic of a neodymium laser or the second harmonic of a ruby laser, $\lambda_p \approx 350 \text{ nm}$ ^[2,3,5-7]; the radiation of an ultraviolet N_2 laser operating both in the single-pulse regime and in a regime with a large pulse repetition frequency^[4]; and the radiation from flash lamps^[8].

Perhaps the only untested presently-suitable (in principle) scintillator-laser excitation sources were radiation-pumping sources.

5. An important property of lasers using organic compounds in general and scintillators in particular is the possibility of continuously varying the generation frequency in a very wide range. Such a variation was realized in a laser with para-terphenyl^[4]. To this end, one of the resonator reflectors was in the form of a diffraction grating with $N = 200$ lines/mm. Rotation of the grating led to a change of the generation wavelength in the range 330–360 nm, i.e., the range of continuous variation was $\Delta\lambda = 300 \text{ \AA}$ ($\Delta\nu = 2500 \text{ cm}^{-1}$) at a generation line width 7 \AA . Further narrowing of the generation line is possible, down to hundredths of an Angstrom^[9].

6. When account is taken of the possible frequency variation, scintillator lasers realized by now fill entirely the spectral region from 330 to 420 nm. There

is no doubt that scintillators can be used to extend the band to 300 nm. It is not presently obvious that still shorter wavelengths can be attained by this method. There is, however, a clear-cut other method for obtaining sufficiently powerful tunable radiation in the region $\lambda < 300 \text{ nm}$. This is the generation of summary frequencies, by starting with organic-compound lasers and their pumping.

Calculation shows that the standard crystals used in nonlinear optics (KDP, ADP) and the already available organic-compound lasers make it possible to obtain radiation at any wavelength in the range from 215 to 330 nm. Experiments performed in this direction have shown that the conversion efficiency is the same as in harmonic generation, i.e., the radiation of organic-compound lasers has no particular distinguishing features capable of lowering the efficiency of mixing it with the radiation of lasers (or its harmonics) used for pumping.

¹B. I. Stepanov and A. N. Rubinov, *Usp. Fiz. Nauk* 95, 45 (1968) [*Sov. Phys.-Usp.* 11, 304 (1968)].

²G. A. Abakumov, L. B. Rubin, A. P. Simonov, V. V. Fadeev, and L. A. Kharitonov, Fourth All-Union Symposium on Nonlinear Optics, Kiev, 1968.

³G. A. Abakumov, A. P. Simonov, V. V. Fadeev, L. A. Kharitonov, and R. V. Khokhlov, *ZhETF Pis. Red.* 9, 15 (1969) [*JETP Lett* 9, 9 (1969)].

⁴G. A. Abakumov, V. V. Fadeev, M. Kasymdjanov, L. A. Kharitonov, R. V. Khokhlov, and A. P. Simonov, Conf. on Non-linear Optics (September 8–12, 1969), The Queen's University of Belfast, Great Britain.

⁵R. G. Huth and G. I. Farmer, *IEEE J. Quantum Electron.* 4, 427 (1968).

⁶V. D. Kotsubanov, Yu. V. Naboikin, L. A. Ogurtsova, A. P. Podgornyĭ, and F. S. Pokrovskaya, *Opt. Spektrosk.* 25, 727 (1968).

⁷T. F. Deutsch and M. Bass, *IEEE J. Quantum Electron.* 5 (5), 260 (1969).

⁸H. Furumoto and H. Cecon, *Appl. Phys. Lett.* 40 (10), 4204 (1969).

⁹D. J. Bradley, A. F. Durrant, G. M. Gale, M. More, and P. D. Smith, *IEEE J. Quantum Electron.* 4 (11), 707 (1968).

A. P. Sukhorukov. Thermal Self-action of Intense Light Waves

The propagation of light waves in absorbing media was investigated until recently within the framework of allowance for the complex character of the dielectric constant. Yet in the case of intense waves it is impossible to disregard the other side of the dissipation processes, namely the heating of the medium. The change in the properties of the medium with increasing temperature, particularly of the refractive index, $n = n_0 + (dn/dT)T$, can greatly influence the conditions for propagation of bounded light beams. Indeed, uneven heating of the medium leads to the formation of thermal lenses that are continuously distributed along the beam.

As shown by recent investigations, thermal effects play a predominant role among other self-action mechanisms, such as the high-frequency Kerr effect,