Fig. 4. Time dependence of the laser pulse.

Fig. 5. Power output as function of buffer gas pressure at optimum delay. Δ —Ar; $\bullet$ —He; $T = 500^\circ\text{C}$; $T_d(\text{He}) = 200\ \mu\text{s}$; $T_d(\text{Ar}) = 450\ \mu\text{s}$.

ometer, model 585. Measurements of pulse shape and duration (Fig. 4) were made with a p-i-n diode terminated by $50\ \Omega$ and a Model 475 Tektronix oscilloscope.

The pulsewidth reported here, 24 ns, is an order of magnitude wider than that reported by Liberman *et al.* [4]. This width is consistent with the observation that laser operation was dependent on the existence of a cavity, whose roundtrip time was 7 ns. This time is also nearer to that reported for other copper lasers [5], including a CuCl vapor laser [2].

We have also investigated power dependence on pressure and type of buffer gas (Fig. 5). Lasing was achieved more easily and over a wider pressure range with helium than with argon. The minimum dissociation pulse voltage required to operate the laser with helium was about 7 kV, while with argon 16 kV was necessary. There was no difference in minimum pumping voltage [6]. The reason for the dissociation voltage difference seems to be the higher electron temperature achieved in the helium discharge. Both higher voltage and lower pressure were needed to achieve lasing in argon. Thus it would seem that a hollow cathode configuration would improve the performance of the CuI vapor laser [7].

Reducing the pumping capacitor from 0.2 to $0.012\ \mu\text{F}$ increased the power output by 20 percent, which suggests that the reduced rise time compensated the reduced overall charge, such that in both cases the current during the first 25 ns was about the same.

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On the Stability of Modes in a Laser Resonator with an Active Medium

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Abstract—A discussion is given on the stability of laser modes; particularly for those in active resonators having negative gain profiles.

One of the most fundamental properties of any laser resonator is the fact that radiation generated in a laser is only present in a number of stable well-defined (sometimes of very complex structure) amplitude and phase distributions of the electromagnetic field at certain frequencies. In a normal continuous or quasi-continuous wave oscillator these stable distributions are independent or quasi-independent of time and they are called the modes of the resonator. The characteristics of a mode are fully determined by the geometry and

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optical properties of the cavity and by the plasma parameters of the active medium. Immediately after the discovery of the laser, the mode patterns of the system were the subject of intensive and detailed study. In this respect, the papers of Fox and Li [1] and Kogelnik and Li [2] can be regarded as classics. Also, for unstable resonators, comprehensive studies have been made (see, for example, the survey paper of Siegman [3]). These papers, dealing only with passive resonators, have value mainly because of the excellent fit shown between the experimentally observed intensity patterns of small cavities and the theoretical calculations. The stability of such modes and how such a mode builds up in time, however, are only fragmentarily studied.

In a recent publication [4] we calculated the mode structure of active resonators for the case where diffraction losses are small, starting from the basic work of Kogelnik [5]. We found that for a stationary state an eigenmode with a Gaussian distribution satisfies the boundary conditions for any quadratic radial gain profile; positive as well as negative ones. As a stability criterion we used the existence of an eigenmode. The justification for the stability of the calculated modes comes, of course, from experiments. For instance, it is not difficult to achieve a high-gain CW CO₂ laser oscillating in the fundamental mode [6]. For such a CO₂ system the small-signal gain has, at high-power excitation conditions due to thermal heating, a minimum in the center of the tube [7]. Moreover, because of saturation, the high intensity of the beam in the center of the tube lowers the actual gain considerably, so that in such a system a large negative gain profile (with the smaller gain at the axis of the tube) exists. Still, from the theoretical point of view, there seems to be doubt about the stability of modes in laser systems with a negative profile, because Casperson [8] and, somewhat similarly, Ganiel and Silberberg [9] try to prove mode instability for such laser systems.

In [8] and [9] the authors describe essentially the behavior of an arbitrary Gaussian pattern through a sequence of identical amplifiers and then they apply the conclusions to an oscillator. Amplifiers only transform the beam parameters by the medium and optical components, but there is no resonance effect. The absence of a resonance condition is the essential difference between an oscillator and an amplifier. For a high-quality oscillator there is the extra condition that only those fields can bounce back and forth for which the phases are not changed after a round trip through the resonator. This means that radiation that does not fit in eigenmodes of the oscillator, because of frequency, amplitude, or phase distributions, will not be amplified to a substantial level. Following the time behavior of a radiation field in an oscillator these nonfitting parts of the field can be neglected as compared with the fitting parts of the field.

A procedure to determine the time behavior can be as follows (this procedure can describe stability as well as the starting process). Suppose in a laser oscillator a certain field distribution is present at a given time t_0 . When looking for stability of a mode this time point will be chosen just after a disturbance has taken place. Also spontaneously emitted radiation will be present. This radiation is in general distributed over both space and frequency.

A part of this field can be expanded in terms of the cavity eigenmodes having specific frequencies. The remaining part will disappear anyhow due to interference because of the lower quality factor of the resonator for this remaining field. Thus only the part of the radiation field that is expanded into the cavity eigenmodes can be amplified to a reasonable level.

The time behavior of the strengths of these expanded modes is rather complex. The time-dependent intensity of a mode is subject to diffraction losses, available gain, out-coupling losses,

competition effects, etc. In the steady state, however, the strength of each mode comes from the equilibrium between the gain and all relevant losses. Some modes may even disappear. This, for instance, may be the case because they are below threshold, or because a finite aperture discriminates higher order modes due to higher diffraction losses. In this way, it is possible that one observes only a zero-order mode with low diffraction losses. Then the radial intensity pattern can to a good approximation be described by the infinite aperture theory; i.e., a pure Gaussian distribution as given in [4]. Anyhow, whatever the gain profile and the cavity parameters are, as long as eigenmodes can be found for such a system stable oscillations will be obtained.

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Fuels for a Premixed Pulsed HCl Laser

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Abstract—HCl pulsed chemical lasing was obtained from several premixed R-Cl/HI mixtures when initiated by a transverse pulsed discharge. The relative merits of these mixtures were compared to a premixed H₂/Cl₂ mixture. For a constant stored electrical energy several mixtures have been found which give higher specific power than the H₂/Cl₂ system. In addition, it has been possible to run some of these improved mixtures without diluent with no laser performance degradation.

The first pulsed chemical HCl laser was reported by Kasper and Pimentel [1] in 1965. Since then, several workers [2]-[7] have studied various fuel systems which produced HCl lasers using both flashlamp and pulsed discharge initiation

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