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High - Power Lasers and Applications

Editors

K. - L. Kompa and H. Walther

High-Power Lasers and Applications

Proceedings of the Fourth Colloquium on Electronic Transition Lasers in Munich, June 20–22, 1977

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Dr. KARL LUDWIG KOMPA

Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.
Projektgruppe für Laserforschung
D-8046 Garching bei München, Fed. Rep. of Germany

Professor Dr. HERBERT WALTHER

Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.
Projektgruppe für Laserforschung und
Sektion Physik der Universität München
D-8046 Garching bei München, Fed. Rep. of Germany

Dr. DAVID L. MACADAM

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Preface

The High-Power Lasers and Applications Conference was held in Munich, June 20 - 22, 1977. The conference took place simultaneously with the "Laser 77, International Congress and Trade Fair" at the Munich Fair Ground. The meeting was a continuation of a series of colloquia on electronic transition lasers previously held in the United States. The main topics of the conference were: high-power VUV, UV, visible and IR lasers, including an analysis of laser systems, technology and laser concepts. Also, some applications to nonlinear optics, chemical kinetics and spectroscopy, particularly with respect to isotope separation, were discussed.

The conference was attended by 95 scientists representing Austria, Canada, England, Finland, Germany (FRG), Germany (GDR), France, Israel, Italy, The Netherlands, and the U.S.A.

The organizers acknowledge financial support from the Deutsche Forschungsgemeinschaft, the U.S. Air Force Office of Scientific Research, the U.S. Air Force European Office of Aerospace Research and Development (EOARD) and the U.S. Army European Research Office, as well as from the companies Coherent Radiation, Spectra Physics and Cryophysics.

Furthermore, we thank our colleagues Dr. Steven N. Suchard and Professor Jeffrey I. Steinfeld for coordinating the U.S. contribution to the conference. We are grateful to Frau Maischberger for administrative assistance.

Karl Ludwig Kompa
Herbert Walther

December 1977

Contents

Part I

Excimer Lasers

Excimer Lasers

Ch.A. Brau

University of California, Los Alamos Scientific Laboratory
Los Alamos, NM 87545, USA

A number of excimer lasers have now been demonstrated spanning the spectrum from green to the vacuum ultraviolet, and others have been proposed. Although the different classes of excimer lasers have rather different properties, making them useful for different purposes, the rare gas halides have demonstrated the highest power and efficiency, and promise to be the most widely useful. Overall efficiency in excess of 1% and pulses as large as 350 J have been achieved from krypton fluoride, and higher efficiency and much larger pulses are predicted. A wide variety of uv wavelengths is available using stimulated Raman scattering.

Excimers are molecules which are bound in an electronically excited state but not in the ground state, and emit characteristic broad band, bound-free radiation. See Fig. 1. The bound-free nature of the laser transition assures

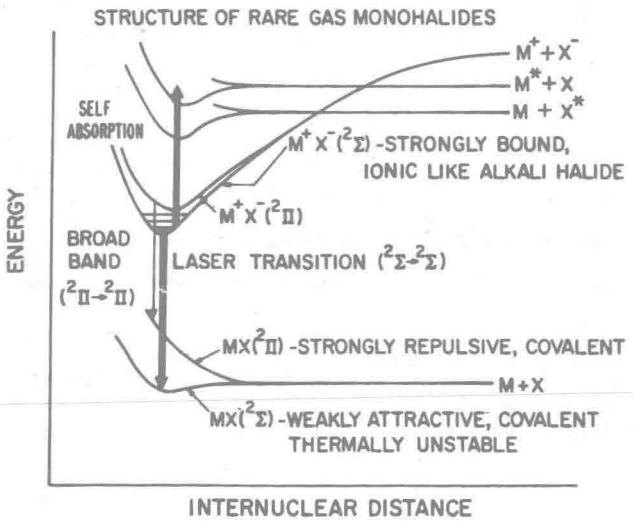

Fig. 1 Potential energy diagram of rare gas halide molecule showing laser and self-absorption transitions.

an inversion and prevents bottlenecking in the lower laser level. However, while the broad band nature of the transition offers some tunability, it also lowers the gain, causing excimer lasers to have high threshold pumping powers. Several classes of excimer lasers have now been demonstrated, including the rare gas oxides, the rare gas monohalides, and mercury (gain only). Similar lasers, in which the lower laser level is bound but in which lasing takes place to a point near dissociation limit, include hydrogen, sodium, the halogens and the recently discovered mercury monohalides. As summarized in Table I, the wavelengths of excimer lasers span the spectrum from green to the vacuum ultraviolet. Other excimer lasers have been proposed and are actively being investigated, including complexes of mercury and the rare gases with various metal atoms. However, the most successful excimer lasers have been the rare gas monohalides, which are the only excimer lasers now available commercially. These lasers have demonstrated high efficiency and high pulse energies previously available only at infrared wavelengths. However, they have their difficulties and limitations as well. Because of their current importance, the remainder of this talk is addressed to the rare gas monohalides.

Table 1. Wavelengths of Excimer Lasers

Species	Wavelength (nm)	Reference
Xe_2	172	Koehler, et al., Appl. Phys. Lett. 21, 198 (1972)
Kr_2	146	Hoff, et al., Appl. Phys. Lett. 23, 245 (1973)
Ar_2	126	Hughes, et al., Appl. Phys. Lett. 24, 488 (1974)
XeO	540	Powell, et al., Appl. Phys. Lett. 25, 730 (1974)
KrO	558	Powell, et al., Appl. Phys. Lett. 25, 730 (1974)
ArO	558	Hughes, et al., Appl. Phys. Lett. 28, 81 (1976)
XeBr	282	Searles and Hart, Appl. Phys. Lett. 27, 435 (1975)
XeF	353	Brau and Ewing, Appl. Phys. Lett. 27, 435 (1975)
XeCl	308	Ewing and Brau, Appl. Phys. Lett. 27, 350 (1975)
KrF	249	Ewing and Brau, Appl. Phys. Lett. 27, 350 (1975)
ArF	193	Hoffman, et al., Appl. Phys. Lett. 28, 350 (1976)
KrCl	222	Murray and Powell, Appl. Phys. Lett. 29, 252 (1976)
Hg_2	335	Schlie, et al., Appl. Phys. Lett. 28, 393 (1976)

To better understand the performance of the rare gas halides, a few words about the spectroscopy and kinetics of these systems are in order. The laser transitions are strongly allowed, with lifetimes of the order of 10 ns and gain cross sections in excess of 10^{-16} cm^2. However, there are also many photoabsorbers in the ultraviolet, including the halogen molecules and a number of transient species such as excited rare gas atoms and excimers, rare gas dimer ions, halogen negative ions, and even the excited rare gas halide molecules themselves.

The basic reason for the higher power and efficiency of the rare gas halide lasers rests in very favorable kinetics for the formation of the upper laser level. The result of electrical excitation of rare gas mixtures is to produce excited rare gas atoms, ions, and electrons. These form rare gas halides in reactions such as

$$Kr^* + F_2 \rightarrow KrF + F \qquad (1)$$

and

$$Kr^+ + F^- + Ar \rightarrow KrF^* + Ar. \qquad (2)$$

Both these processes are very rapid, occurring in times typically of the order of 10 ns. In many cases these reactions are essentially 100% efficient in producing excited rare gas halide products. However, the excited products are quenched by rapid processes as well, such as

$$KrF^* + F_2 \rightarrow Kr + 3F, \tag{3}$$

and

$$KrF^* + Kr + Ar \rightarrow Kr_2F^* + Ar. \tag{4}$$

To achieve the high pumping rates needed to reach threshold, several techniques have been used, including high intensity, relativistic electron beams, fast transverse discharges, and electron beam stabilized discharges. In the future direct nuclear pumping may be accomplished using a pulsed nuclear reactor to initiate fission reactions in the laser. When electron beams are used to pump the laser, the relativistic electrons form excited rare gas atoms and ions, with an average energy $\bar{W} \tilde{>} 20$ eV deposited in the gas for each ion or excited state produced. Thus, in a KrF laser with a photon energy $h\nu$, the maximum possible efficiency is $\eta(\max) = h\nu\,(KrF)/\bar{W}\,(argon) = 25\%$. Intrinsic efficiencies (laser energy ÷ deposited in gas) as high as 15% have been observed from KrF [1], but overall ("wall plug") efficiencies have been much lower [2]. Using a large area electron beam, pulses as large as 350 J have been obtained from KrF [3]. Larger pulses are possible, but ultimately the pulse energy becomes limited to something of the order of a kilojoule per meter of laser length by problems of closure of the electron beam gun and self pinching of the electron beam. The overall length of the laser is limited by photoabsorption processes but pulses as large as kilojoules appear possible. The pulse repetition frequency and, therefore, the average power are limited by the rate at which the foil (through which the electron beam enters the laser) can be cooled and the laser medium cleaned up by flow and acoustic damping.

Discharges are potentially more efficient than electron beams since it takes less energy to form an excited rare gas atom with a thermal electron than it takes to form an ion with a relativistic electron. Except in helium [4], more than 80% of the discharge energy can appear as electronic excitation of the rare gas [5]. See Fig. 2. The maximum possible efficiency is limited, of course, by the ratio of the photon energy $h\nu$ to the rare gas excitation energy E*. Thus, in a KrF laser $\eta(\max) = h\nu(KrF)/E^*(Kr) = 50\%$. In practice, much lower efficiencies are observed for a number of reasons. Discharges in electronegative gases are fundamentally unstable and if they are not stabilized externally the impedance rapidly collapses, after breakdown, and spatial nonuniformities develop. Thus, such discharges cannot be operated at optimum conditions. Nevertheless, simple, low inductance, fast transverse discharges have produced pulses larger than 700 mJ, with a pulse length of the order of 20 ns and an overall efficiency (laser energy ÷ stored energy) in excess of 1% [6]. A pulse repetition frequency of 100 Hz has been demonstrated in a separate experiment [7]. Increasing the pulse repetition frequency by more than an order of magnitude appears possible, but will depend on advances in switching technology. Larger pulses can be achieved by using electron beam ionization of the gas to stabilize the discharge [8]. Pulses as large as 50 J and as long as 300 ns have been achieved this way [3]. However, the electric field and, therefore, the gain are limited in such discharges, making efficient extraction of the laser energy difficult. See Fig. 2.

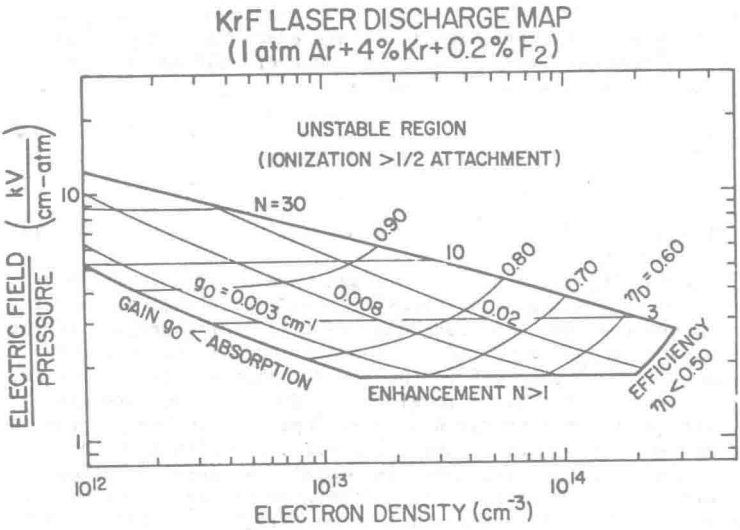

Fig. 2 Operating map for discharge-pumped krypton fluoride laser using Ar with 4% Kr and 0.2% F_2 at 100 kPa total pressure

The pulse length and wavelength of the rare gas halide lasers can be modified in a number of ways. Pulses as long as 1 μs have been achieved with electron beam pumping [9], but pulses longer than 10 μs become limited by consumption of the molecular halogen in the gas and the growth of medium inhomogenieties. Short pulses can be obtained by mode-locking, with a minimum pulse length limited by the duration of the gain pulse [10]. Shorter pulses can be amplified within the available bandwidth, but the short lifetime and high gain of the rare gas halides prevent them from storing large amount of energy to be extracted in a single large pulse. When large, short pulses are needed, the rare gas halides may be useful as efficient, powerful pumps for other lasers, such as the iodine photodissociation laser [12], or it may be possible to use Raman pulse compression techniques [13]. Wavelength shifting may also be accomplished in a number of ways. XeF (351 nm) lasers can be used to pump visible laser dyes, and KrF (248 nm) lasers have been used to pump dyes for the near uv region [14]. It should be possible to achieve at least discrete tunability deeper into the uv by pumping other, simpler molecules. Stimulated Raman scattering has been used to shift XeF (351 nm) to 585 nm in barium vapor [15], and a multitude of wavelengths throughout the uv have been achieved by Raman scattering KrF and ArF radiation from H_2, D_2, CH_4 and liquid N_2 [16] (see Fig. 3). In the future, much shorter wavelengths may be possible by tripling (4-wave mixing) the rare gas halide lasers, as has been done with Xe_2 lasers [17].

The power and efficiency of the rare gas halide lasers should make them useful for a variety of applications. For chemical processing, rare gas halide laser photons are available for only pennies per mole (for the electricity) and their use for separating oxygen [18] and hydrogen [19] isotopes

SRS-Generated UV Wavelengths

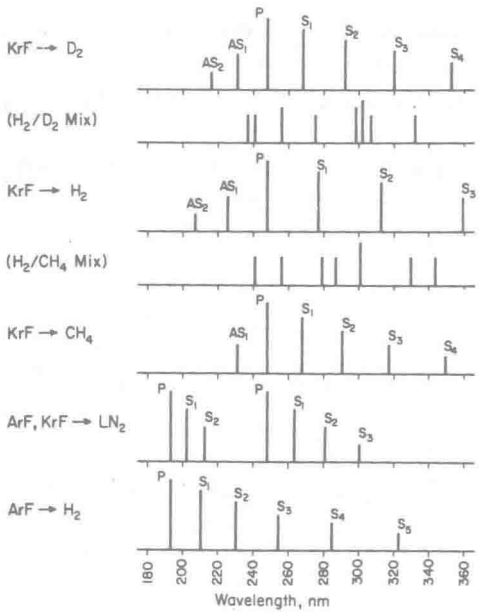

Fig. 3 Wavelengths achieved by stimulated Raman scattering of ArF and KrF lasers.

has already been discussed. In the future they may be useful for micromachining, lithography, deep space communications, remote sensing of the atmosphere, optical radar, or anywhere that intense, cheap uv photons are needed.

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