data plot has the same general shape as the theoretical one, but that it is displaced to higher voltages. We find that by dividing the observed voltage by a factor of 1.3, the data will fit on the theoretical curve. As of yet, we have found no direct reason for this discrepancy.

Using high-frequency filters, we have been able to detect radiation in excess of 150 GHz with the present resonator structure. These high-frequency signals are probably due to the interaction of the electron beam with higher-order waveguide modes, since the gain, although smaller, is not negligible. The power of the 150-GHz signals is 1 W at the diode junction and may be much higher if one takes into account the sensitivity of the detector diode [1N53] at 150 GHz.

In conclusion, the above experiments have demonstrated the ability to use the Cerenkov interaction produced when a relativistic electron beam is accelerated through a dielectric-lined waveguide, as a tunable source of high-power, short-wavelength radiation. We have observed the basic dependence of the output frequency on electron beam energy and have detected microwave signals in excess of 150 GHz at significant power levels.

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A microwave-pumped XeCl* laser

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A XeCl* excimer laser excited by 2-μs-long, 9.375-GHz microwave pulses has been constructed. Spontaneous emission times of $\sim$500 ns have been observed, while the maximum laser pulse length was 100 ns. The laser pulse length appears to be limited by the buildup of a transient loss.

PACS numbers: 42.55.Hg, 42.60.By, 52.80.Pi

We have constructed a long-pulse 308-nm XeCl* excimer laser excited by high-power microwave (9.375 GHz) pulses. Electron-beam, avalanche-discharge, and electron-beam-sustained discharge pumped excimer lasers have been studied extensively[1–4] and each have different advantages and limitations. Microwave pumping retains the practical simplicity of the avalanche discharge, while avoiding its extreme sensitivity to discharge conditions. The pulse length and efficiency of avalanche-discharge lasers are limited by the formation of plasma arcs, which make it impossible to maintain adequate excitation rates throughout the volume. The sensitivity to such factors as detailed gas composition, electrode irregularities, degree and uniformity of preionization,and the characteristics of the driving source have been described in detail by Levatter and Lin. [5] They note that, except for their own work [6] using high-power x-ray preionization and very fast rise -time drivers, avalanche-discharge laser pulse lengths have been limited to about 10 ns.

In contrast, microwave excitation of high-pressure gases is much less sensitive to the details of the plasma: the power deposition is nominally independent of gas composition, uniform preionization is not critical, and even a local breakdown or arc does not prevent effective excitation in other regions of the plasma. In addition, the device is easily constructed with high-vacuum, halogen-compatible materials. As a result, we have been able to observe spontaneous XeCl* emission for periods of up to 500 ns and to produce 100-ns laser pulses using a very simple apparatus.

A Varian SFD-303 coaxial magnetron and line-type pulser provides 600-kW, 2-μs-long pulses at 9.375 GHz. The pulses have a rise time of about 100 ns and travel through $\sim$8 m of x-band waveguide pressurized with SF_6 to the active laser region, illustrated in Fig. 1. The microwave energy is coupled from the primary guide into a secondary guide containing a concentric 3-mm i.d. quartz tube holding the laser gas mixture. The gas mixture is slowly recirculated through an all-stainless-steel closed loop system. Although the magnetron is capable of 400-Hz operation, thermal shock effects combined with our slow flow rates limited operation to 10 Hz. In addition, the recirculating pump limits absolute pres-

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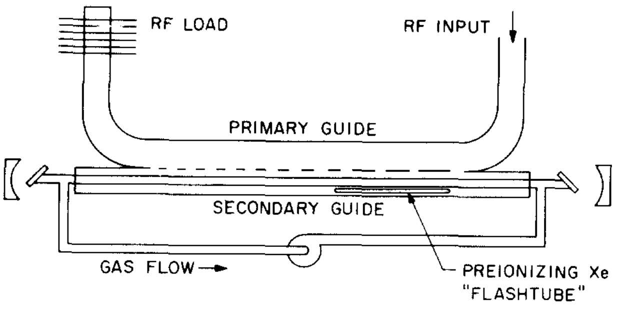

FIG. 1. Schematic of the microwave-pumped XeCl* laser. The Brewster windows are CaF$_2$ and the cavity consists of 2-m-radius mirrors 1 m apart.

sures to about 2 atm.

The microwave coupler consists of a series of "Riblet Tee" slots,[7] which are spaced to provide nearly uniform transfer of microwave energy from the primary to secondary waveguide along the 40-cm-long coupling region. Using this coupler, 80–90% of the energy in the primary guide can be absorbed in a variety of rare-gas–halogen-buffer gas mixtures at pressures between 1 and 3 atm, yielding a power deposition of $(1–2)\times 10^5$ W/cm^3. Once the discharge is initiated the power reflected to the source is insignificant.

The microwave discharge is more stable and reproducible if it is initiated by a small amount of preionization. This is accomplished by placing a ~ 12-cm- long sealed quartz tube containing ~ 1 Torr of Xe in the secondary guide. This low-pressure Xe "flash lamp" breaks down early in the microwave pulse providing simple, self-timed UV preionization of the laser mixture.

Laser action in XeCl* was observed at several wavelengths centered at 308 nm. The net round-trip gain was just over 20% using a mixture consisting of 0.3% Xe, 0.05% HCl, and 99.6% Ne at a total pressure of 2 atm. Figure 2 shows the relative time behavior of the microwave, spontaneous fluorescence, and laser pulses. The laser pulse length had a maximum value of 100 ns and was inversely proportional to the output coupling (Fig. 3), while the spontaneous emission lasted for over 500 ns. It seems likely that the pulse length was limited by a transient loss which built up during the pulse.[8] Our optimum gas mixture corresponds closely to the one given in Ref. 8, which minimizes such transient losses, while it differs considerably from the mixtures normally used for avalanche-discharge lasers.

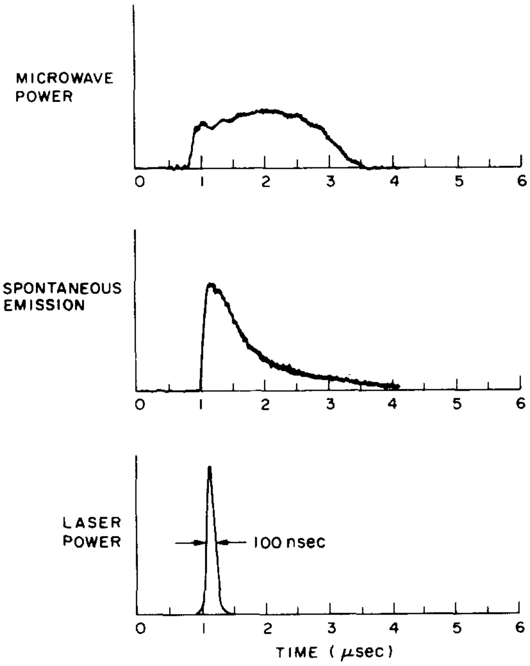

FIG. 2. Relative time behavior of the microwave power, XeCl* spontaneous emission, and laser pulses.

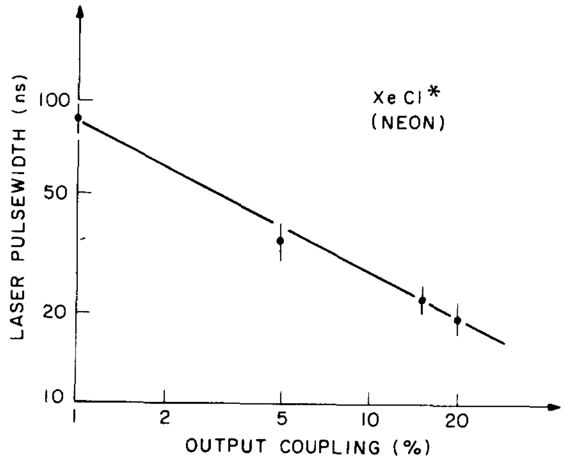

FIG. 3. Laser pulse width vs output coupling, log-log scales.

The peak laser output power was only ~ 20 W with 5% output coupling, giving an overall efficiency of less than 0.01%. In the present design, however, the efficiency is significantly reduced by the small fraction of the discharge volume which is used by the laser mode. A more useful figure is the formation efficiency, defined as the ratio of the energy stored in the XeCl* exciplex to the input microwave energy. Using the measured 20% gain and the stimulated cross section for XeCl*, this is calculated to be 0.2%. The spontaneous-emission intensity increases with microwave input power and total pressure as shown in Fig. 4, indicating a potential for higher power and efficiency.

We have demonstrated that microwave pumping is a simple technique for producing relatively long pulse excimer

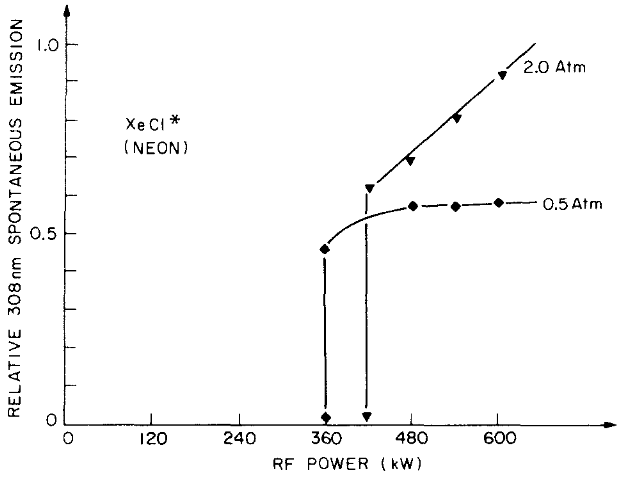

FIG. 4. Intensity of 308-nm spontaneous emission as a function of microwave power and total pressure.

lasers. Such a system may be useful for generating well-controlled mode-locked pulses for a high-power amplifier chain. In addition, the microwave pumping scheme lends itself to applications where long gas lifetimes and hands-off operation are required because of the all metal and quartz construction and the absence of eletrodes with their sputtering problems.

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Buried convex waveguide structure (GaAl) As injection lasers

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A new channeled substrate (GaAl)As double-heterostructure laser with mode control as well as internal current confinement is described. The narrow active region (3–3.5 μm) surrounded by GaAlAs is buried in the etched channel, around which a reverse-biased heterojunction is formed. The threshold current is as low as 20 mA cw, and highly stable fundamental-mode lasing is observed.

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Channeled substrate (GaAl) As double-heterostructure (DH)] lasers were first reported by Burnham *et al.*[1] and Kirkby *et al.*[2] and were later modified to improve lasing characteristics.[3–5] To achieve low-threshold current in channeled substrate lasers, the structure with a convex active region which results in a higher effective refractive index at the center portion is more advantageous than the structure with a planar active layer. However, it is supposed that the channeled substrate lasers with a convex active region do not consistently succeed to realize single-fundamental-mode lasing.[5,6] This may be the reason that the active-region width is much larger to cut off the higher-order-mode lasing. In this letter, we report a new channeled substrate (GaAl) As DH laser called a buried convex waveguide structure [BCS] laser in which mode control as well as internal current confinement are realized. In BCS lasers, a convex active region (3–3.5 μm wide) surrounded by GaAlAs is buried in an etched channel and is also aligned with the reverse-biased heterojunction formed outside the etched channel. The cw threshold current is as low as 20 mA, and highly stable single-fundamental-mode lasing is observed.

A scanning electron micrograph of the cleaved cross section of an as-grown BCS wafer and a schematic diagram of the BCS laser are given as Fig. 1. The BCS wafer is prepared by a two-step liquid-phase epitaxy technique. In the first growth stage, a three-layer structure is grown on a (100) GaAs substrate. The three layers are composed of (i) n-$Ga_{0.7}Al_{0.3}As$ (1 μm thick), (ii) p-$Ga_{0.7}Al_{0.3}As$ (0.3 μm thick), and (iii) n-GaAs (0.3 μm thick). The GaAs top layer enables the reproducible growth of GaAlAs and GaAs in the second-growth stage,[7] and also provides the reverse-biased heterojunction for internal current confinement. After the first growth, 4-μm wide and2–2.5-μm-deep channels along the (011) orientation on the wafer are etched by using conventional photolithography. In the second-growth stage, the n-$Ga_{0.7}Al_{0.3}$ As is grown so that the etched channel is only partially filled. Then a p-$Ga_{0.96}Al_{0.04}$ As active region is grown about 0.1 μm thick in the center portion of the channel. Finally, p-$Ga_{0.7}Al_{0.3}$ As and p-GaAs layers are grown so as to fill the channel completely. The growth rate in the

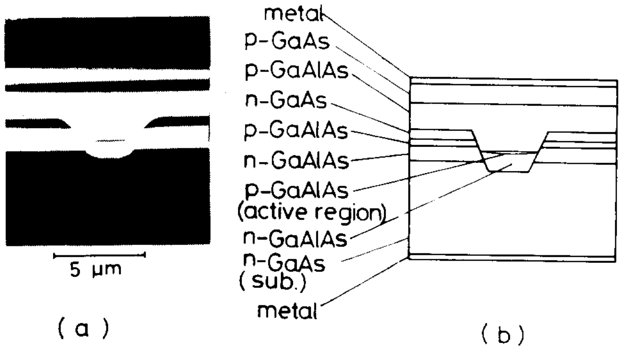

FIG. 1. Buried convex structure (BCS) laser, (a) scanning electron micrograph of (as)-grown wafer, and (b) schematic diagram.