Continuous wave near-infrared atomic Xe laser excited by a radio frequency discharge in a slab geometry

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Near-infrared atomic Xe laser lines have been generated from an Ar:He:Xe laser gas mixture excited by a radio frequency (rf) discharge in a slab geometry. A maximum continuous wave (cw) output power of 1.5 W (270 W/l) was obtained at an rf frequency of 125 MHz from a gas mixture containing Ar:He:Xe (50:49:1) at a total gas pressure of 90 Torr. © *1995 American Institute of Physics.*

There is a steady growing interest in sources of coherent radiation which operate in the wavelength region of 2–3 μm.[1] Possible applications of such systems include the design of eye-safe radars,[2–4] the monitoring of the atmosphere and in medicine.[5–7] Until now the research in this wavelength region was concentrated mainly on the improvement of solid state lasers made from YAG and YLF crystals doped with rare earth metals like holmium, erbium, and thulium which are capable of operating in a pulsed mode as well as cw. So far, there are no other lasers capable of delivering a cw output on a reasonably high power level in this spectral domain.

Recently, we published the first results concerning a new cw rf excited Ar:He:Xe laser with an output power of about 300 mW.[8] This laser operates in a multiline mode with 90% of the output concentrated in the two strongest atomic Xe lines: the $5d[3/2]^1-6p[1/2]^0$ transition with a wavelength of 2.65 μm and the $5d[3/2]^1$-$6p[3/2]^1$ transition at 2.03 μm. In principle, this laser competes with the abovementioned rare earth doped solid state lasers which also emit their radiation in the same spectral range and are reported to operate at the same power level.

In this letter, we report on a different approach to enhance the output power of such an rf excited atomic Xe laser. By using a laser resonator in a planar configuration which is homogeneously filled with a gas discharge plasma we were able to increase substantially the volume of the active medium. It resulted in an increase of the output power to a maximum value of 1.5 W and also improved the efficiency with a factor 4 compared to our earlier results.[8] We have tested several electrode and resonator configurations. The experimental setup is discussed in more detail elswhere.[8.9] Here we will give only a brief description of the equipment used in our experiments. A signal from a low power master oscillator was amplified in a wide band rf amplifier (Kalmus, model 124C) which is capable to deliver a rf output power of 500 W in the frequency range of 10 kHz–220 MHz. The forward and reflected rf power was measured with a digital power meter (Thruline 4421 from Bird Electronics Corp.). The excitation frequency used in our experiments was varied between 100 and 125 MHz. The frequency choice in each particular case was determined by the resonance conditions for the RLC circuit formed by the discharge impedance, the capacitance of the laser structure, and the inductance of the shunting coils connected parallel to the laser electrodes. The construction of the laser head used in the experiments was basically the same as used in Ref. 8. The ground electrode was cooled with tap water while the high voltage electrode could be cooled with a closed cycle refrigerating system with the possibility to cool down the electrode to −10 °C.

In the planar configuration the following electrode widths were used: 2.25, 8, and 10 mm. The interelectrode distance was varied from 0.5 to 2.5 mm. All electrodes were made out of aluminum and had a length of 370 mm. Two flat mirrors were used for the resonantor. The total reflecting mirror was a quartz substrate coated with gold, the dielectric output mirror, also based on a quartz substrate, reflected 45% in the spectral range 1.7–3.5 μm. The total length of the resonator was 40 cm. Ar-He-Xe laser gas mixtures were used at a total pressure ranging from 60 to 400 Torr. The Ar content of the gas mixture was varied from 30% to 100%, the amount of Xe was 1% in all experiments. The laser output power was measured with a Melles Griot optical power meter.

The highest output power of 1.5 W was obtained for a gas mixture consisting of Ar:He:Xe (50:49:1) at a pressure of 90 Torr. The excitation frequency was equal to 125 MHz and discharge volume was $1.5\times10\times370$ mm^3. The efficiency of the laser under these conditions was 0.44%. The laser efficiency was defined as the ratio of the laser output power and the total electrical energy deposited in the discharge. The laser efficiency depends on the input power and under certain conditions increases as the power deposition into the discharge increases. In Fig. 1 the output power and laser efficiency are shown for Ar:He:Xe(50:49:1) at a pressure of 90 Torr as a function of the power input. The output power and efficiency grow with the increase of the power input. Generally, an upper limit for the input power loading was imposed by a breakdown of the gas between the high voltage electrode and the wall of the laser chamber. For this reason we

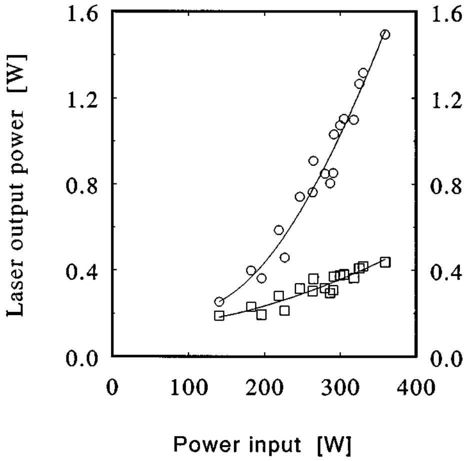

FIG. 1. Laser output power (○) and efficiency (□) as a function of input power for the gas mixture Ar–He–Xe (50:49:1) at a pressure of 90 Torr as a function of the input power.

could not determine the optimum conditions for these two parameters. It was also found that the efficiency grows with the increase of the Ar concentration in the gas mixture. On the other hand, a higher concentration of argon limits the power deposition into the discharge because of instabilities that occur at elevated input power levels especially at a low gas pressure. In fact it was not possible to work at a pressure lower than 100 Torr with more than 100 W power input in an Ar-Xe gas mixture. It was possible to get a maximum efficiency of 0.8% with a mixture of Ar:He:Xe=79:20:1 at a total gas pressure of 90 Torr and an input power of only 120 W.

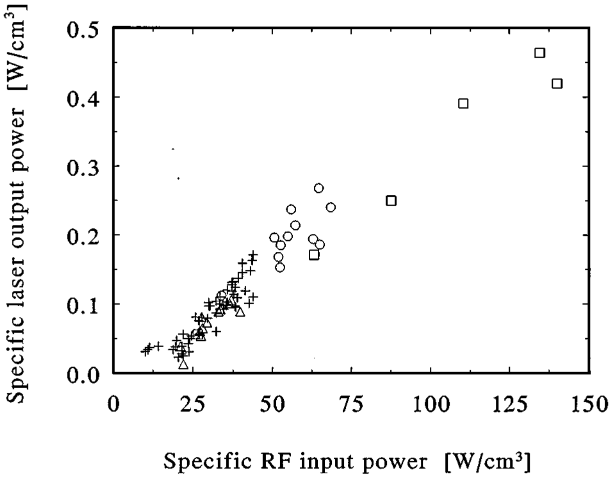

FIG. 2. Specific laser output as a function of the specific rf input power for the different laser channel configurations. The laser channel cross sections are 2.5×8 mm^2 (+), 2.5×10 mm^2 (△), 1.5×10 mm^2 (○), and 0.5×10 mm^2 (□).

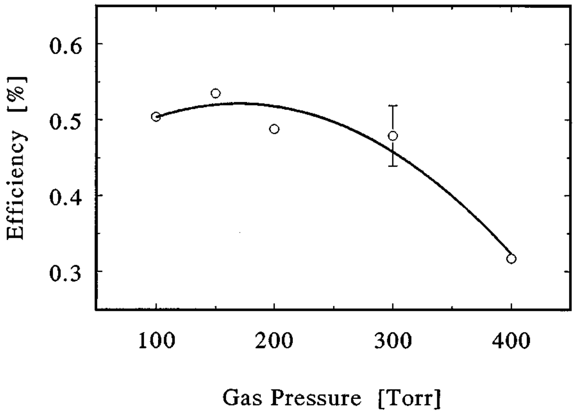

FIG. 3. Laser efficiency as a function of the gas pressure. The gas mixture is: Ar:Xe=99:1 and the rf input power 95 W.

The maximum output power of 1.5 W corresponded to a specific output power density of 0.27 $\mathrm{W/cm}^3$. In this case the specific input power was ~65 $\mathrm{W/cm}^3$. (It was possible to vary the discharge volume from 2 to 9 cm^3, the specific input power density could be changed in the range from a few $\mathrm{W/cm}^3$ to more than 100 $\mathrm{W/cm}^3$.) By variation of the active volume we were able to obtain the dependence of the specific output power on the input power. This dependence for an Ar:He:Xe(50:49:1) gas mixture at pressures ranging from 60 to 150 Torr and for cross sections of the laser channel of 2.5×8, 0.5×10, 1.5×10, and 2.5×10 mm^2 is shown in Fig. 2. The maximum specific output power of 0.46 $\mathrm{W/cm}^3$ (total output 0.86 W) was reached at a specific input power of 135 $\mathrm{W/cm}^3$ and with a cross section of the laser channel of 0.5×10 mm^2. Despite the different working conditions one can see that the specific power output almost linearly grows with the increase of the specific power input. This means that within this pressure range the efficiency is almost constant. At higher pressures the output power increases (although not linearly) while the efficiency decreases with increasing pressure as can be seen in Fig. 3.

One of the important items that still remains unclear is the generation mechanism that leads to continuous wave lasing at this power level. It is commonly accepted that in high pressure *e*-beam sustained systems the upper laser levels of neutral xenon are populated by recombination and dissociation of ArXe^+ ions which are formed in three particle collisions in the plasma.[10] This population mechanism suggests that the lasing characteristics will improve as the operating pressure of the gas mixture increases. For that reason we performed experiments in a pressure range up to half an atmosphere. The inconsistency of the data shown in Fig. 3 with our results from pulsed experiments at multi-atmospheric pressures[11] may be attributed to different discharge conditions and/or formation kinetics. Perhaps due to this different excitation mechanism laser action on the well-known atomic Xe laser line at 1.73 μm is absent in all our experiments. These phenomena challenge us to continue with our investigations of the lasing mechanism.

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