A CW high specific output power Ar-He-Xe laser with transverse RF excitation.

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Abstract

A transverse RF excited gas discharge recently for the first time has been successfully used to produce a CW Ar-He-Xe laser. A maximum output power of 330 mW has been obtained from an experimental device with 37 cm active length and a $2.25 \cdot 2.25$ cm^2 cross-section. This corresponds to a specific output power of about 175 mW/cm^3. Under these preliminary optimum conditions the gas pressure was 85 Torr (Ar:He:Xe=59:40:1). The laser output spectrum consisted of 5 atomic xenon lines (2.03, 2.63, 2.65, 3.37 and 3.51 μm). The 2.03 μm and 2.65 μm lines were the strongest ones.

Complementary to this device a quartz capillary was tested as laser tube for the atomic Xe laser. With this configuration it was possible to sustain a longitudinal DC as well as a transversal RF discharge in the laser gas mixture. Combined excitation was also possible for this device. This enabled us to compare the laser performance in both the DC and the RF mode in the same device. Preliminary measurements showed us that the highest output power in the DC mode was less than 1 mW, while the RF excited laser yielded about 130 mW. The gain coefficient was found to be extremely high. Laser generation was obtained for a wide range of reflectivities R of the outcoupling mirror. At the minimum reflectivity of 5% still an output power of 20 mW was obtained. Results obtained from both systems will be discussed.

Introduction

The pulsed atomic Xe laser recently showed high efficiency operation combined with high output energy[1-3]. The laser generally oscillates on several lines ranging from 1.73 to 3.37 μm covering an important band in the near infrared part of the spectrum. The spectral region around two micron coincides with a strong absorption maximum of water. That makes future sources of coherent radiation that will operate at these wavelengths especially attractive for a number of potential applications. The most important areas are laser surgery and atmosphere monitoring[4]. The advantage of a laser scalpel based on a two micron laser is that compared to Nd-YAG lasers its radiation has a much higher absorption in human tissues, although not as high as CO_2 laser radiation. But, on the other hand, radiation around 2 μm has rather small propagation losses in silica based fibers and this is not the case for 10.6μm radiation.

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In these application fields two main possible groups of competitors exist namely solid-state lasers based on the rare earths doped crystals and Ar-(He)-Xe lasers. An important advantage of Ar-Xe lasers is that they can deliver much more energy. However solid state lasers are more compact and, that is even more important for the applications mentioned above can operate in a CW mode. The appearance of simple, compact and inexpensive Ar-Xe lasers could change this situation drastically.

To pump the atomic Xe laser several well known excitation techniques have been used such as optical pumping by means of the UV radiation[5] , thermal ionising radiation from plasmadynamic discharges[6], e-beam[7,8] and e-beam sustained[9] discharges, longitudinal discharges[10], transverse electrical atmospheric discharges[11,12] and even excitation with fission fragments[13,14]. All these excitation techniques have been applied in a pulsed mode although in some devices pulse lengths of several milliseconds have been obtained[1,7,13,14]. Also RF and microwave excitation in a waveguide structure have been used but only in a pulsed or burst mode. In 1980 Christensen et al.[15] reported an output power of 30 mW from an active volume of 0.9 cm^3 in a 25 µs pulse with an RF excitation frequency of 30 MHz. In 1988 the same group of NRL reported output pulses as long as 8 µs from a waveguide laser excited with microwave radiation with a frequency of 915 MHz[16]. RF excitation of rare gas mixtures such as He-Ar and Ar-Xe were also investigated by a research group at Hughes Aircraft Company. They achieved 4.5mJ per pulse or 100 mW average power at 20 kHz pulse repetition rate with an efficiency of 0.1 %[17]. It was pointed out here that the rare gas based neutral gas laser systems prefer short excitation pulses with pulse lengths of 0.5 to 1 µs. Longer pulses did not increase the output power. These results were confirmed by the recent experiments made by E.D.Protsenko and co-workers[18] who operated an Ar-Xe laser in a pulsed mode for pressures up to ~ 1 atm. They measured a specific output power of 5mW/cm^3 for 1 µs pulses. Continuous wave lasing has been reported from both DC and longitudinal RF excited devices working at very low pressures[19-21]. The maximum output power obtained in those experiments was usually a few milliwatts.

The first results on a continuous wave atomic Xe laser pumped by a transverse capacitively coupled RF discharge in the medium pressure range have been recently published[22]. In this paper we present some further results on our the investigations on different excitation schemes of a CW Ar-He-Xe laser with direct transverse RF excitation by a capacitively coupled discharge, a transverse RF excitation through a dielectric and DC excitation as well as combined DC+RF excitation.

Experimental setup

The experimental setup consists of a vacuum-tight laser head made of aluminum which simultaneously serves as the container for the gas mixture as well as the housing for the laser electrodes. A discharge channel was formed by two stainless steel electrodes and two dielectric sidewalls. As the Fresnel number for the longest wavelength observed in the experiments was about 1 it can be concluded that the dielectric properties of these sidewalls were not important with respect to the radiation propagation losses. The electrodes and sidewalls formed a discharge channel with a cross section of 2.25*2.25 mm^2. The length of the active medium was 37 cm. The ground electrode was cooled with tap water while the high-voltage electrode remained uncooled. A totally reflecting gold coated mirror with a radius of curvature of 1 m and an outcoupling mirror (plane-parallel uncoated silicon window) formed the laser resonator of about 40 cm length. Four shunting coils have been connected in parallel to the laser electrodes to produce a homogeneous axial voltage distribution, which resulted in a non-homogeneity of the voltage less than 3%. An L-type matching circuit between the laser head and the RF power amplifier with an upper frequency limit of 220 MHz enabled us to work within a 0.5 to 1% power reflection range. The excitation frequency was set at 121 MHz. No optimisation of the excitation frequency has been performed although some different excitation frequencies were used. A bi-directional coupler was installed between the amplifier and the matching circuit to measure the input and reflected power levels. The RF power attenuated by the coupler was subsequently measured with a Hewlett-Packard (HP 437B) power meter. The laser output power was monitored with a broad band power/energy meter (Melles-Griot model BPEM 001). Two techniques were used to measure the spectral composition of the laser radiation. Rough on-line estimations of the laser output spectrum were performed with a set of narrow band optical filters which blocked all but one of the possible laser lines. We used five filters for the following wavelengths 1.73, 2.03, 2.63 & 2.65, 3.37 and 3.51 μm. To separate the 2.63 and 2.65 μm laser line we also used a monochromator with a 150 l/mm grating blazed at 2 μ m. It was also used for monitoring the weak laser lines. A liquid nitrogen cooled Ge-Au detector was used to monitor the signal.

A set of experiments has also been performed with another experimental configuration. A quartz tube was used to confine the discharge instead of the metal-dielectric construction described above. The design of the tube enabled us to operate with DC excitation, transverse RF excitation or in a combined (DC+RF) mode. The RF discharge was excited through the dielectric tube walls. Two platinum electrodes were used in the DC mode. In the combined mode the discharge was sustained by the simultaneous application of DC and RF fields perpendicular to each other. Four shunting coils were found to be sufficient for the homogeneous distribution of the RF voltage along the electrodes. In this case the laser resonator was formed by a totally reflecting internal mirror (R=80cm) and an externally mounted partially transmitting mirror. Different reflectivities ranging from 95% to 5% have been tested. A ZnSe plate was used as a Brewster window. Measurement procedures and techniques used in these experiments were essentially the same as for the first construction.

Experimental results and discussion

We preliminary investigated the performance of the laser as a function of gas composition and RF input power with the first mentioned setup. Mixtures with a different gas composition starting from a helium free Ar:Xe=99:1 and finishing with an argon free He:Xe=99:1 mixture have been studied. With the laser working in the CW mode it was found that for binary mixtures the laser output was rather low, generally less then 10 mW. The discharge behaviour differed for these binary mixtures dramatically, however. With the helium-free mixture it appeared to be almost impossible to get a stable discharge while in argon-free mixtures the discharge remained fairly stable for pressures up to 350 Torr. The best results with respect to the laser output power have been obtained with ternary mixtures. A typical example of the laser output power as a function of the input power is shown in Fig. 1. The laser head was filled with a gas mixture Ar:He:Xe=39:60:1 at a total gas pressure of 90 Torr. The laser power increases with the pumping power. The laser efficiency is plotted in the same figure and is more or less constant at 0.2% for the higher output power levels.

We did not perform a complete optimisation procedure with respect to the optimal gas composition or cavity configuration. Until now a maximum output power level of 330 mW for a gas mixture Ar:He:Xe=59:40:1 at 86 Torr was obtained. Spectral measurements of the laser output have been performed with the experimental technique mentioned above. It was found that the laser spectrum contained at least 4 lines with wavelengths of 2.03, 2.63 and/or 2.65, 3.37, and 3.51 μm. A typical spectrum of the laser output is presented in Fig. 2. The line intensity distribution may be influenced by the outcoupling etalon which had a free spectral range of about 20 GHz. It is also confirmed by some correlated changes in the output power of 2.03μm and 2.65μm laser lines. All observed lines are attributed to the 5d-6p transition of the Xe atom. Under our experimental conditions the maximum output power was obtained from the $5d[3/2]_1 \rightarrow 6p[3/2]_1$ transition with a wavelength of 2.03μm. The laser spectrum observed in our experiments was somewhat different from the one typical for the high-pressure pulsed atomic Xe laser. The 1.73 μm laser line was not observed because of the high He concentration. On the other hand the 3.51 μm transition found in our experiments normally appeared only at very low gas pressures[19,20].

The experiments with the quartz laser tube and DC excitation confirmed the well known results obtained for the atomic xenon laser by other researches. Some typical results for the laser output power as a function of DC input for the gas mixture Ar:He:Xe=50:49:1 are shown in Fig. 3. An outcoupling mirror with a reflectivity of 95% at 2.65 μm line was used. The pressure was changed within the range 10 - 50 Torr; further changes lead to a rapid decrease in output power. Combined excitation gave essentially the same results: the output power never exceeded the 1 mW level for the whole range of the discharge parameters such as relative DC/RF input power, discharge current, gas composition, etc.

The situation differs substantially when only a transverse RF excitation is applied to the laser tube. The output power appeared to be more than two orders of magnitude higher than in the same setup but with the DC excitation. In Fig. 4 and 5 some typical results are presented. The laser power as a function of the RF input power is presented for the different gas compositions. Gas mixtures Ar:He:Xe=50:49:1 (Fig. 4) and Ar:He:Xe=80:20:1 (Fig. 5) were investigated. In both cases an plane parallel Ge plate was used as an outcoupling mirror. The output power was more than two orders of magnitude higher than the one obtained in the DC mode for the similar power depositions.

The extremely high gain coefficient initially observed in the early experiments with neutral xenon lasers[19,20] was also observed in our case. Different reflectivities for the outcoupling mirror starting from 95% and ending with 5% were used in our experiments. A typical curve that shows the output power of the 2.65 μm line as a function of mirror reflectivity is shown in Fig. 6. Some irregularities in its form can be explained as a result of the change in the transmission of uncoated plane parallel plates acting as an etalon. Still, it is interesting to mention that even with the minimum reflectivity of 5-6% an output of about 20 mW was available.

In conclusion, experiments performed with several devices all producing CW Ar-Xe laser output proved that this type of laser can be a promising new source of coherent radiation in the 2 μm range. The investigations in this field are now in progress. Our preliminary results show that CW lasing with an output power of more than 1 W probably can be obtained in the near future.

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Figure 1

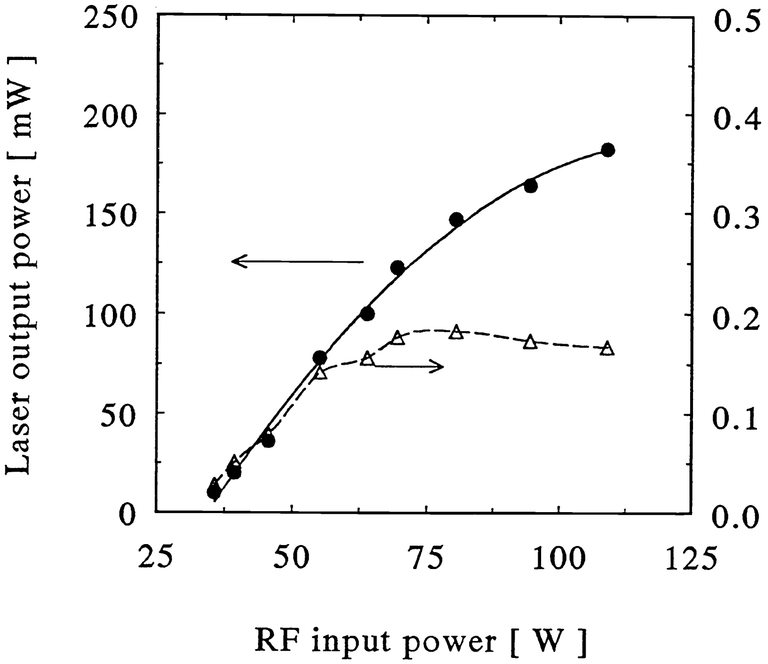

Figure 2

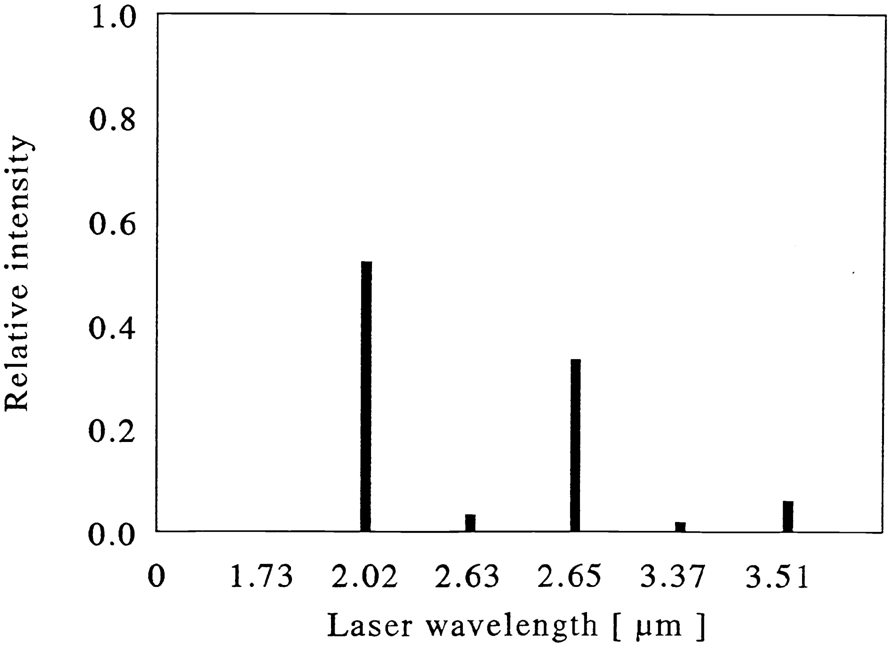

Figure 3

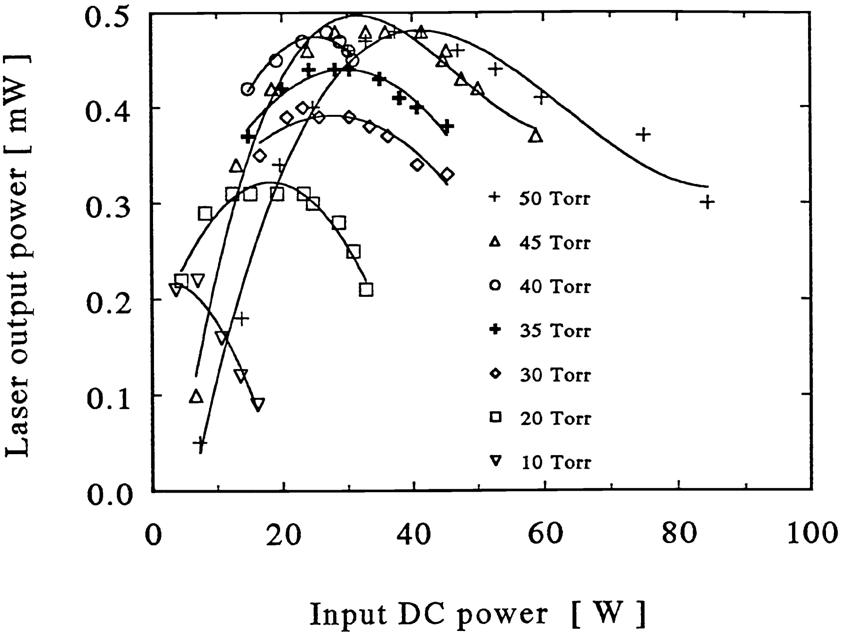

Figure 4

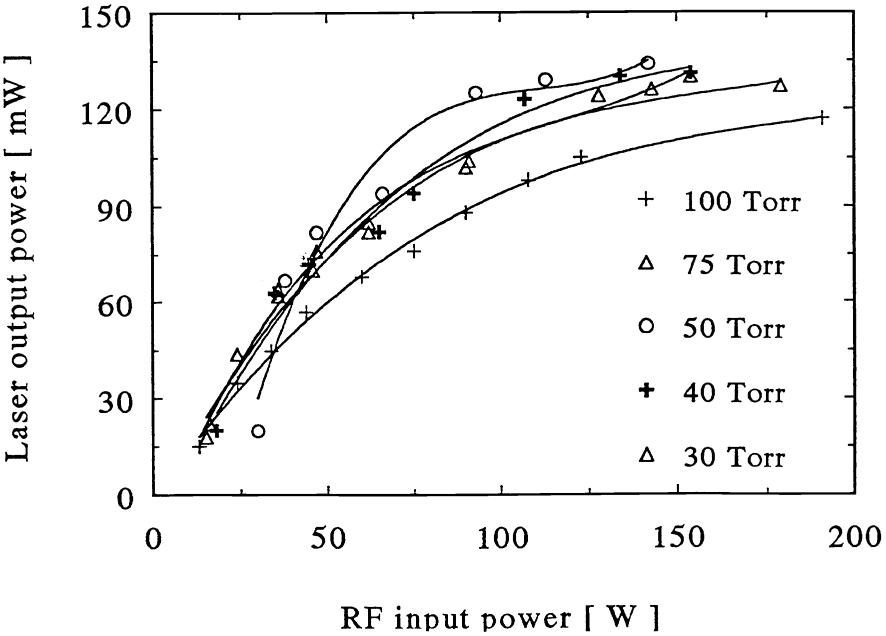

Figure 5

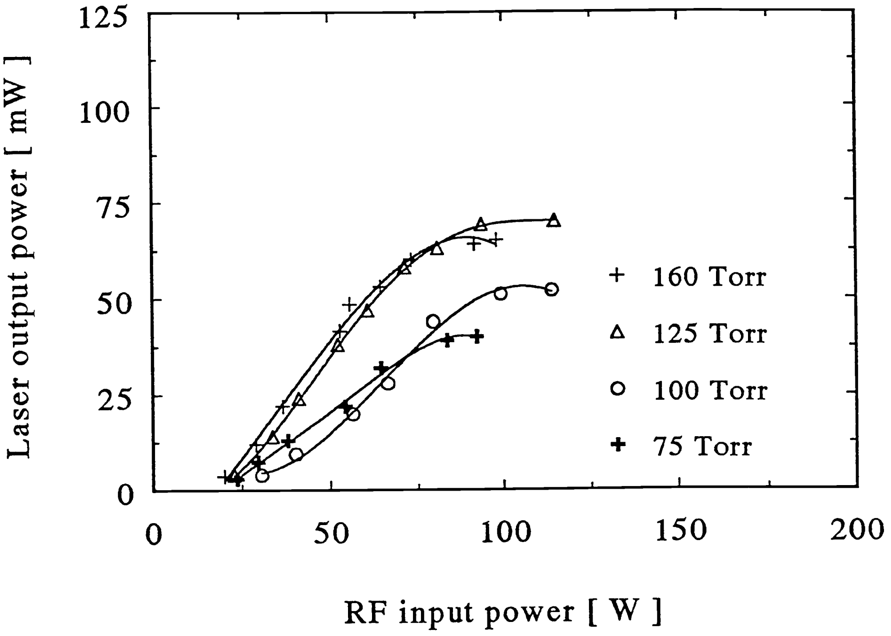

Figure 6