THE EFFECT OF ADDITION OF BUFFER GASES ON THE OUTPUT ENERGY AND PULSE WIDTH OF AMMONIA LASER

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Abstract

We present the design of a pulsed ammonia laser, which is optically pumped by a TEA CO_2 laser. The effect of addition of buffer gases to the ammonia gas laser (such as N_2, He and Ar with different mixing ratios) on the output energy and pulse width of the laser was studied. It was found that N_2 gas was preferable among the other additives as it provides highest output pulse energy and increasing the laser efficiency. The addition of N_2 gas helped also in obtaining more than 40 ammonia laser lines around the 12µm, which was step tunable in the spectral range of (762-968 cm^{-1}).

تأثير الغازات المخمّدة المضافة الى ليزر الامونيا على الطاقة الخارجة وزمن نبضة الليزر

الخلاصة

تم تصميم ليزر الامونيا النبضي المضخ ضوئيا باستعمال ليزر ثاني أوكسيد الكربون نوع TEA ، ودرس تأثير اضافة احدى الغازات المخمّدة (N_2 , He ,Ar) الى ليزر الامونيا بنسب خلط مختلفة على طاقة الليزر وزمن نبضته المتولدة.لقد وجد ان غاز النتروجين أحسن هذه الغازات تأثيرا حيث ساعد في الحصول على أعلى طاقة نبضه، ورفع بدرجة كبيرة من كفاءة الليزر، كذلك ساعد اضافة النتروجين في الحصول على اكثر من 40 خط طيفي من ليزر الامونيا (باطوال موجية حول 12 مايكروميتر) وبتوليف ترددي متقطع في المدى ($762\ cm^{-1} - 968$) .

Introduction:

Mid-infrared optically pumped molecular gas lasers have attracted a great interest as potential sources in photochemistry [1-3].The ammonia molecules, when optically pumped by TEA CO2 laser lines, has been one of the most powerful and spectrally rich molecules to generate mid infrared (MIR) laser lines around 12 µm.

The addition of buffer gases such as N_2, He and Ar to the ammonia molecular gas enhances the laser output by a great factor, so that a high output of ammonia laser was obtained, which can be attributed to the high thermal conductivity of these gases.

Experimental

The ammonia laser system was designed and constructed in a previous work, with an output energy of about 12 mJ before adding any buffer gas, it is shown schematically in figure (1-a, b). Three optical arrangements were used for the ammonia cavity, in the first arrangement (free running cavity) the laser cavity is formed between a dielectric coated ZnSe mirror (M1) (radius of curvature 7 m, reflectivity of 25% at 12 µm wavelengths) and a plane Cu mirror (M2), as shown in figure (1-a). In the second arrangement, the plane mirror M2 was replaced by a 60 line/mm grating (blazed at 12 µm), while in the third arrangement the ZnSe output coupler is replaced by higher reflectivity (70%)

output coupler, in order to enhance those lines with lower oscillation gain.
The cavity length was 165 cm, while the active medium length was 130 cm. The active medium section was terminated at one end by a NaCl Brewster's window, while the other by a ZnSe mirror as an output coupler.
TEA CO2 laser, Lumonics company(model 103), is used as a pumping source and has the following specifications: line tuning by 100 line/mm grating, about 2 J pulse energy pair line, 80 ns pulse width at (FWHM) and spot size dimension of (1.5x2.5) cm^2. The 9R (30) line from a TEA CO2 laser was introduced into the cavity in an off-axis pumping configuration. The ammonia laser output energy was measured by a Lumonics pyroelectric energy detector model 20D, while a HgCdTe detector of rice time about 1 ns and wavelength responsivity at the range of 10-20 µm, was used to detect the output laser power and pulse width, and a ¼ m grating monochromator was used to measure the wavelengths of the generated NH_3 laser lines.

Results and Discussion:

The performance of the optically pumped ammonia laser enhanced greatly by the addition of either of the buffer gases (N_2, Ar, He). A (325) mJ maximum output energy of the ammonia laser was obtained, which can be attributed to the high thermal conductivity of these buffer gases [4], and the laser operates with an efficiency of 16% in a multiline configuration.
There was nearly zero transmitted pump energy (due to the off-axis pumping) even at (5cm) from the ammonia laser output coupler along the direction of the cavity axis, thus no filtering against the pump radiation was necessary in the course of the output energy measurements.
In order to determine the optimal gases composition and the total operating gas pressure of the active mixture of NH_3-N_2, NH_3-Ar and NH_3-He, a study was made of the dependence of the laser output energy on the total operating gas pressure of the mixture for various ratios of the constituents. It was found that the maximum energy was obtained with N_2 buffer gas at the optimal mixture composition of NH_3-N_2 = 1:200 and an optimum total operating pressure of 150 mbar (figure 2). The results may be summarized as follows in table (1):

Table (1): Maximum output laser energy at the optimum mixing ratios of different buffer gases.

Buffer gas	Optimum mixing ratio NH_3 -X	Optimum total operating pressure (mbar)	Maximum output laser energy (mJ)
N_2	1:200	150	325
Ar	1:300	200	180
He	1:200	180	200

The above results can be explained in terms of the following factors in table (2):

Table (2): Physical properties of the buffer gases.

Factors	Buffer Gases		
	N_2	He	Ar
Pressure broadening MHz/Torr [9]	7-8	2.3	3.5
Thermal conductivity Cal/gm.ºK [4]	0.249	1.24	0.12
Relaxation rate $\mu sec^{-1}.Torr^{-1}$ [10]	$1.2*10^{-1}$	$9.3*10^{-1}$	$5.9*10^{-1}$

Such a strong influence of nitrogen on the output energy can be explained by the fact that the nitrogen has rotational-vibration levels that are quasiresonant with the final laser levels, and the collisions of NH_3 with N_2 lead to a rapid depopulation of these levels, which will greatly improve the laser output [5]. The temporal behaviors of the laser pulse as a function of NH_3-N_2 total pressure for different mixing ratios was investigated, figure (3).

Addition of these buffer gases showed that lasing transitions took place in more than 30 lines for free running cavity, and more than 40 lines in a selective grating cavity, and this can be attributed to the fact that the addition of buffer gases has decreased the rotational relaxation time in the excited state, such that $\tau_r < \tau_p$ (pumping pulse width) [6], and this may lead to an equilibrium distribution of the molecules over the rotational levels (j, k) within the duration of the pumping pulse, which can be established in the first excited state of the ν_2 vibrational mode. At a certain pumping rate, the population inversion is produced between the corresponding levels (1, j, k) and (0, j-1, k) [7], thus, only P-branch transitions should have gain [8].

By tuning the grating of the NH_3-N_2 cavity, selective single line oscillation of one of the P-branch transitions was obtained. We have observed more than 40 lines listed in table (3), with its intensities normalized to the strongest line. The output frequencies lie between 968.5 cm^{-1} and 762.2 cm^{-1}, while their pulse shape and width varied from line to line at approximately 1 to 5 μsec (FWHM) at optimal NH_3-N_2 pressure

Table (3): Laser transitions obtained by tuning the cavity grating.
Relative intensities are normalized to the strongest transition (ν = 855.4 cm^{-1})

ν cm^{-1}	Line Strength	ν cm^{-1}	Line Strength	ν cm^{-1}	Line Strength
*968.5	0.24	855.4	1.00	813.5	0.10
934.6	0.03	854.7	0.05	799.7	0.20
932.8	0.02	853.6	0.03	798.7	0.14
932.0	0.14	853.2	0.35	797.4	0.17
930.7	0.11	849.2	0.06	*795.5	0.03
929.4	0.04	836.8	0.03	*793.0	0.05
*927.6	0.02	836.1	0.20	790.5	0.01
909.9	0.14	835.8	0.20	790.2	0.08
894.1	0.07	835.1	0.03	789.6	0.23
890.1	0.04	834.7	0.11	*788.3	0.02
*874.5	0.06	834.0	0.24	781.5	0.01
870.3	0.03	829.5	0.20	780.6	0.05
869.5	0.14	818.0	0.40	779.7	0.17
856.9	0.03	817.0	0.20	777.9	0.01
856.2	0.11	815.3	0.35	773.1	0.02
				772.5	0.20
				762.2	0.02

*Lines obtained using 70% ZnSe output coupler mirror.

Conclusions

1- The wide range step tunability of NH_3-X Laser is attributed to the shortening of the rotational relaxation time of the excited NH_3 molecules by the addition of buffer gases.
2- Continuous tunability can be achieved within the gain profile of each rotational-vibration molecular transition, and this more suitable for high-resolution spectroscopy and IR photochemistry. This can be obtained by increasing the operating pressure of the ammonia laser into a several atmospheric pressure, and also by inserting an intracavity Fabry-Perot etalon and using a raster light guide laser pumping system. The above-mentioned technique requires higher input pumping power.

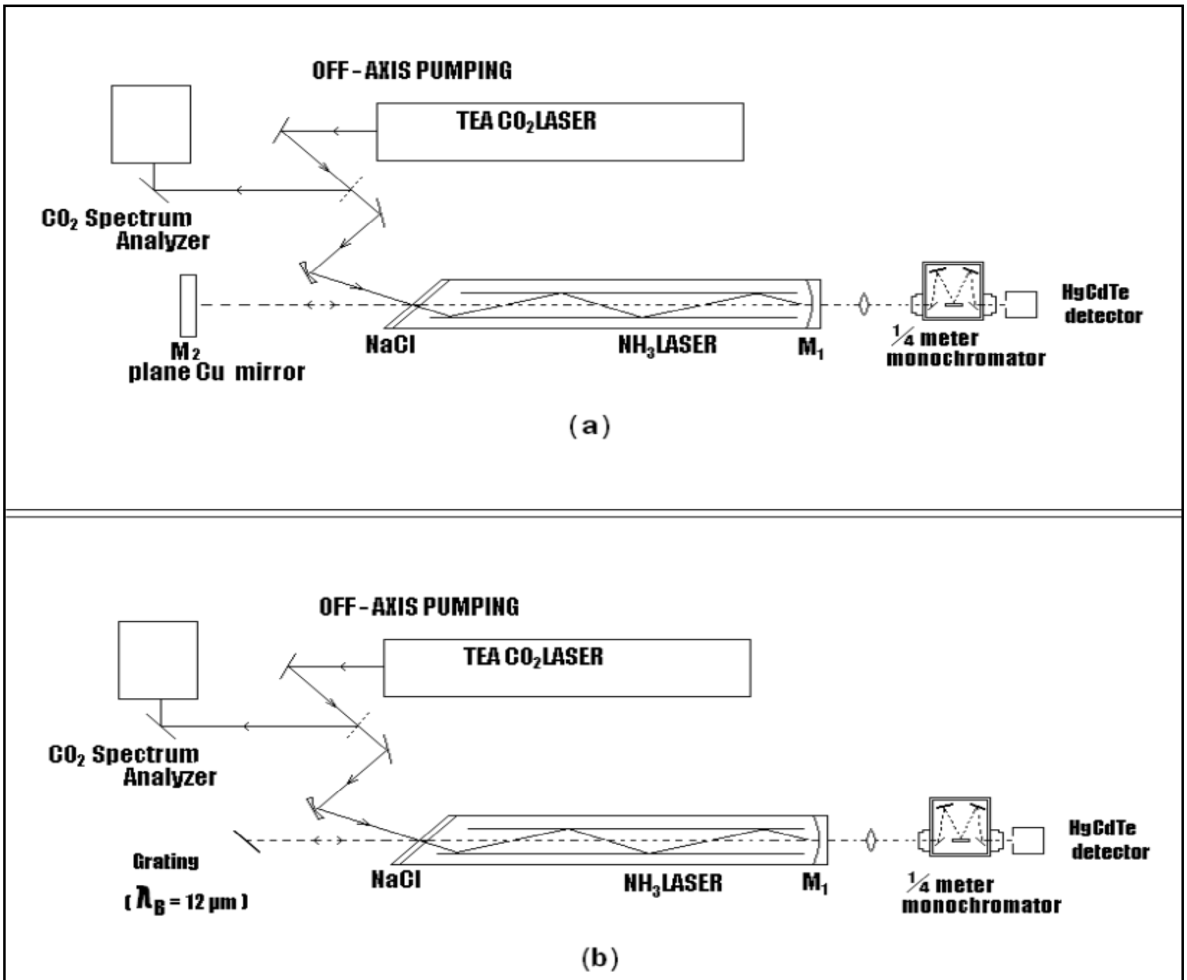

FIG.1 (a,b) EXPERIMINTAL SET-UP

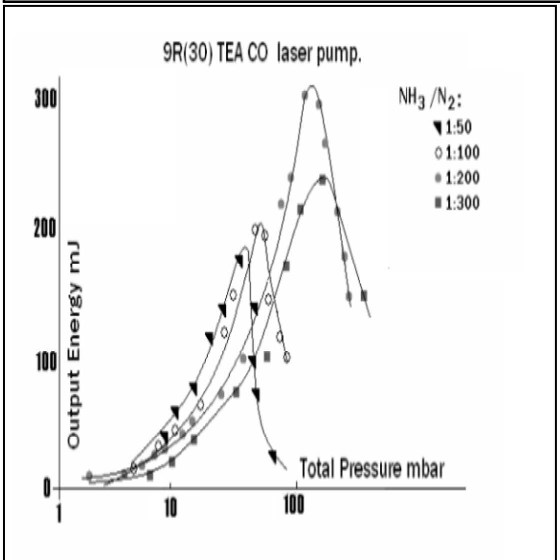

FIG.2 DEPENDANCE OF THE OUTPUT ENERGY ON THE TOTAL PRESSURE OF VARIOUS RATIOS OF NH_3- N_2 MIXTURE.

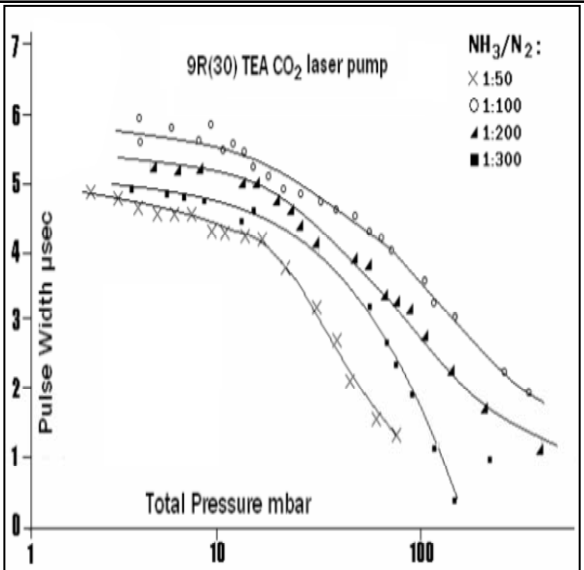

FIG.3 DEPENDENCE OF THE LASER PULSE WIDTH ON THE TOTAL PRESSURE OF VARIOUS RATIOS OF NH_3- N_2MIXTURE.

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