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Intra-Cavity Loss Element Method for Measurement of the Small Signal Gain of a *TEA CO_2* Laser

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ABSTRACT
The small-signal gain coefficient of a *TEA CO_2* laser has been measured through the implementation of a variable polarization intra-cavity loss element. Charging voltage dependence of the gain property of the laser has been investigated. The advantage of this method is that no probe laser system is required. The results have been agreed with experimental data obtained by conventional oscillator-amplifier method.

Key words: TEA CO_2 laser, small-signal gain, intra-cavity losses
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INTRODUCTION

A TEA CO_2 laser as an efficient source of infrared radiation is being increasing utilized in different areas of science and technology. Developed more than 40 years of first reports about TE CO_2 lasers, and during this period some important applications found for these lasers, such as DIAL (Killinger & Menyuk, 1981), non-linear optics in mid-infrared (Kildal & Deutsch, 1976), plasma generation (Haglund, Nowak, & Czuchlewski, 1981), and recently measurement of the temperature of the Alfa particles in the Tokamak (Kondoh et al., 2006). The small signal gain, (g_0), and saturation intensity, (I_s), characteristics are important parameters for the design and scaling of the gaseous lasers.

Although these parameters may be investigated with different methods, such as direct probe or oscillator-amplifier array, the latter technique has been used extensively usually because of the lack of availability of an appropriate tunable laser probe (Behrouzinia, Sadighi-Bonabi, Parvin, & Zand, 2004; Behrouzinia, Sadighi, & Parvin, 2003). There are two standard method for measuring g_0 of CW or pulsed CO_2 lasers; intra-cavity (variable) loss element and oscillator-amplifier methods (Heard & Zipin, 1969). The g_0 has been experimentally studied by the oscillator-amplifier method for an untunable CO_2 laser (Antropov, Silin-Bekchurin, Sobolev, & Sokovikov, 1968; P. Cheo, 1968; Tulip, 1970) at different wavelengths (Dang, Reid, & Garside, 1980; Sato & Miura, 1983) and for a TEA CO_2 laser (PK Cheo, 1967; Nath & Biswas, 1997) The intra-cavity variable loss element is easier to apply relative to the other one, whereas the measurement of the g_0 is only desired. We have been successfully used this method for measurement of g_0 of a CW CO_2 laser earlier (Aram, Soltanmoradi, Ghafori, & Behjat, 2005). To our knowledge, only one report is available on a rare gas Halide pulsed laser based on using an intra-cavity variable absorption gas cell loss element (Armandillo, Kearsley, & Webb, 2000). The g_0 and I_s can be measured at the line center of a single-longitudinal-mode laser, the result of measurements being dependent on the broadening. For CO_2 lasers operating at a normal pressure of about 10 Torr, the homogeneous line broadening dominates at vibration-rotational transitions from the upper (001) level to the lower (02^00, 10^00) levels (Aram, Soltanmoradi, & Behjat, 2004; DeMaria, 1973; Witteman, 1987). The method proposed in this work do not use a probe beam from an auxiliary laser, and therefore, errors due to the instability of the auxiliary laser are eliminated. The g_0 of a TEA CO_2 laser has been measured through the implementation of a variable polarization intra-cavity loss element. The experimental results have been investigated in some different charging voltage.

EXPERIMENTAL SETUP

The laser cell with optical arrangement is shown in Fig.1.

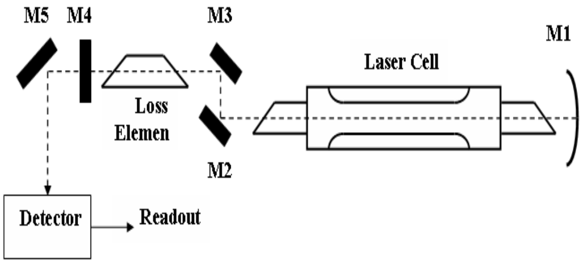

Fig.1 The optical arrangement of the experimental apparatus.

The TEA cell with two Brewster windows have contains the pair of Aluminum electrodes with active volume $2 \times 2 \times 38\ cm^3$ and two rows of ten Aluminum pins as spark array pre-ionizers. A simple capacitor using a N_2 pressurized trigatron switch is used for making the electrical excitation pulse and glow discharge (Aram, Soltanmoradi, & Behjat, 2004).

The home-made polarization loss element is composed of two Brewster windows which one of them can be rotated around the optical axis of two windows, Fig.2. Two high reflection flat mirrors (M_2 and M_3) are used for alignment the axis of loss element and TEA cell. Au coated concave ($R = 5m$) mirror (M_1) and a flat natural *Ge* (M_4), with 180cm apart from each other, are used as back mirror and out-coupler, respectively.

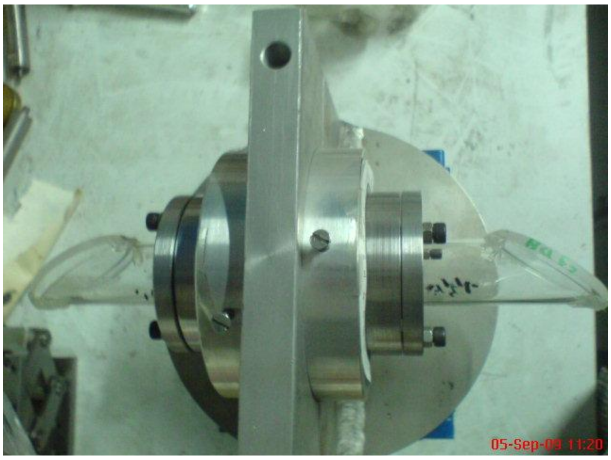

Fig.2 Polarization loss element.

The output energy of laser is measured by a LMP5 pyro-electric joule meter via coherent lab master readout with 1 mj precision. The output laser line was $10P(20)$ most of time without using any line tuning device ,and measured by a CO_2 laser grating spectrometer (Optical Engineering Co.), and it is obviously clear because of the kinetics of depopulation of CO_2 molecule energy levels in high pressure, the $00^01 \rightarrow 10^00$ transition is dominant to $00^01 \rightarrow 02^00$ one (Witteman, 1987).

RESULTS AND DISCUSSION

The variation of output energy versus charging voltage is shown in Fig .3.

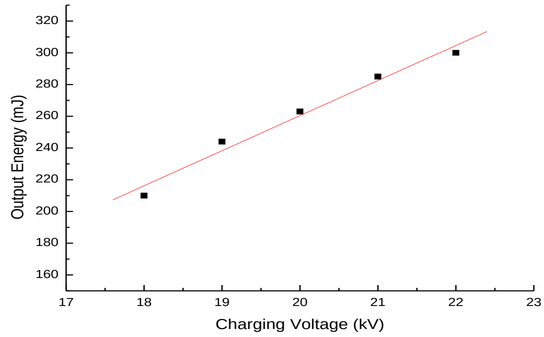

Fig.3 The variation of output energy versus charging voltage.

As can be seen, the output energy is increased linearly by increasing of charging voltage in the interval of $18 \sim 22\ kV$. The variation of g_0^{max} versus charging voltage is shown in Fig .4.

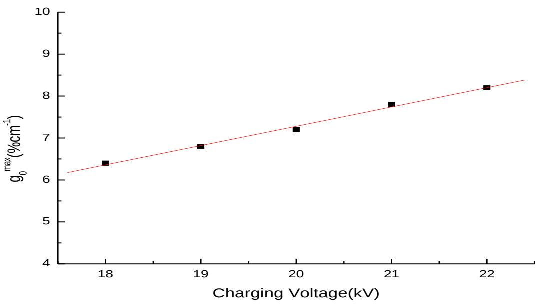

Fig. 4 The variation of g_0^{max} versus charging voltage.

The maximum value of g_0, (g_0^{max}) is increased linearly so, by increasing of charging voltage in that same interval. The, g_0^{max}, is obtained as following procedure. At first, the loss element tuned at minimum loss which corresponds to the maximum output energy, then by rotating one of its windows and tracing the decreasing output energy using the threshold condition, the maximum small signal gain is derived as following formula:

$$g_0^{max} = \frac{(-\ln R - 2\ln a_{min} - 4\ln \cos \Delta\upsilon)}{2Lm} \quad (1)$$

which R is the reflectivity of Ge out-coupler (53% total), α_{min} is minimum loss of the element, which is 10% for single pass, and mainly related to the imperfections in windows and construction of the cell, $\Delta\theta$ is the deviation angle from maximum output relative to threshold condition and L_m is the length of active medium (45 cm).

The loss of the Brewster windows of the TEA cell isn't included because they had high quality, so the diffraction loss of tube aperture is negligible by assumption of having TEM_{00}. Because the single pass time of the cavity is 6 ns and it is smaller than the duration of *TEA* CO_2 gain ($\gtrsim 50\ ns$), the time variation of g_0 near the threshold is neglected. As can be seen from Fig.4, the obtained g_0^{max} is from 6.4 % $cm^{-1}$to 8.2%cm^{-1} , that is the same order with results obtained by others; (Franzen & Jennings, 1972; Singer, 1974), which give the g_0^{max} from 7 % cm^{-1} to 10 % cm^{-1}. It's obvious that the g_0^{max} has been measured at multi longitudinal mode condition, so the spatial hole burning effect is omitted. The most important point is the simplicity of having a good estimate of medium amplification capability and the minimum of reflectivity of the out coupler.

CONCLUSION

Measurement of the maximum small signal gain of a spark array UV pre-ionized *TEA* CO_2 laser via intra-cavity loss element is reported. The advantage of this method is that no probe laser system is required. Simplicity of polarization loss method makes it applicable for many of other lasers, too.

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