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Nondestructive Analysis for HeNe Lasers

The methods used to measure the gas properties in sealed helium-neon lasers are described. Such parameters as total gas pressure, minor constituent concentration (i.e., He/Ne ratio), and gas purity can be measured using spectral emission methods. How these parameters and measurement techniques relate to the electrical operating characteristics of the laser is described.

Introduction

Laser operating life and reliability greatly depend on gas quality. The parameters which govern gas discharge, gas pressure and purity, He/Ne ratio, discharge current, and bore diameter are chosen to yield optimum laser operation. We have used electrical measurements and emission spectroscopy to monitor variations in the gas phase of sealed helium-neon laser tubes. The part of the spectrum examined or the choice of the particular spectral line depends on which property of the gas mixture is being measured: impurity level, total pressure, or He/Ne ratio. The methods were developed using commercially available structures and then applied as needed to the parallel plate laser under development in our laboratory.

Gas purity

The effects of gas impurities on laser output have been described in detail by Hochuli [1] and Turner [2]. Impurities can be introduced into the gas mixture of a laser in the following ways: 1) impure gas at the fill station; 2) inadequate vacuum bake-out during the clean-up cycle; 3) minute or gross leaks in the laser structure; and 4) dissociation of the cathode surface.

The results shown in Fig. 1 are qualitatively similar to the trends reported in earlier work [1, 2]. What is important is the quantitative data which show that relatively high impurity levels (>1000 ppm) can be tolerated in the helium-neon mixture before a degradation of laser power is observed. The data indicate that hydrogen has the most severe effect, followed by oxygen, and then by the relatively harmless nitrogen impurity. The relative insensitivity of the laser output to these high impurity levels is indeed fortunate since gas purity can easily be maintained to within these limits, and thus reactive impurities are not in a practical sense one of the major causes of laser *degradation*.

The major factor which contributes to limiting laser *life* is the loss of gas due to cathode sputtering. This is the aging mechanism observed in a variety of gaseous electronic devices [3], especially those which operate at low pressures. Many factors influencing cathode sputtering are discussed in detail in another section of this paper. One of these is the total pressure. The dependence of sputtering rate on pressure is empirically represented [3] by:

$$\textit{Rate of sputtering} \propto \frac{1}{p^n}, \qquad (1)$$

where n varies between 2 and 5.

It was because of our concern with cathode sputtering, as well as the need to evaluate our processing and fabrication techniques compared to those of commercially available lasers, that we made a series of spectral measurements and extended them to include the evaluation of total pressure and He/Ne ratio.

Gas pressure and He/Ne ratio

The power output of a typical helium-neon laser depends heavily on total pressure. The optimal pressure for a given type of laser is a balance of many factors. For a

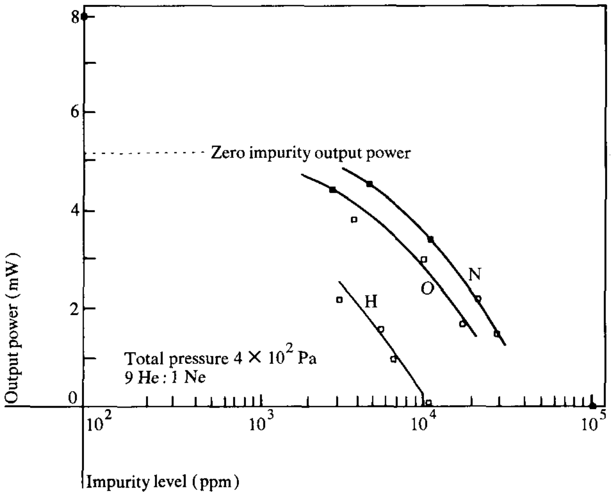

Figure 1 Influence of nitrogen, oxygen, and hydrogen on the laser output power. (Data obtained on the 5-mW laser structure.)

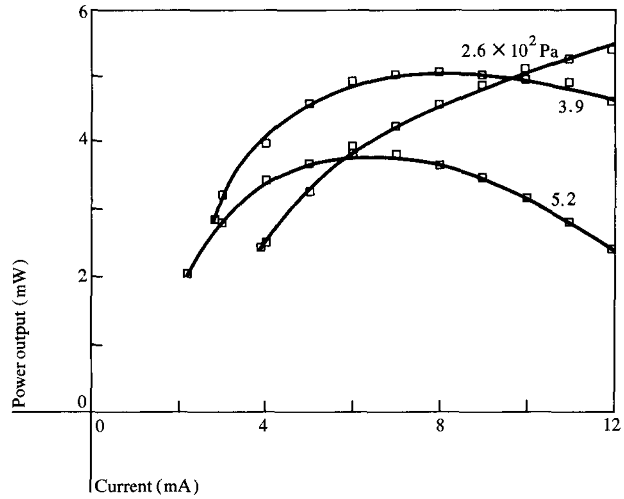

Figure 2 Laser output power as a function of operating current for various pressures (utilizing a 5-mW laser structure).

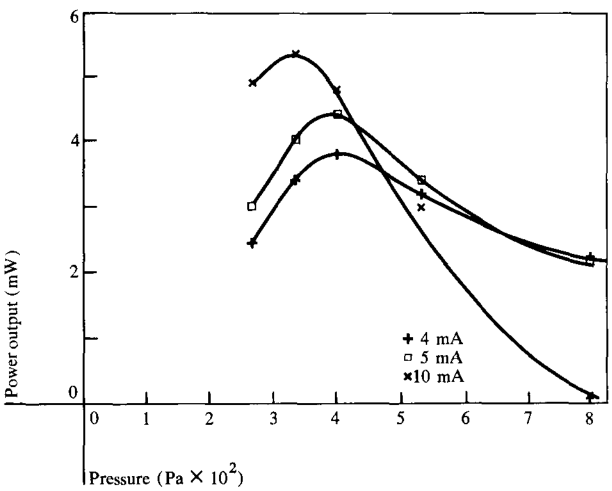

Figure 3 Output power as a function of pressure for various operating currents (Fig. 2, replotted).

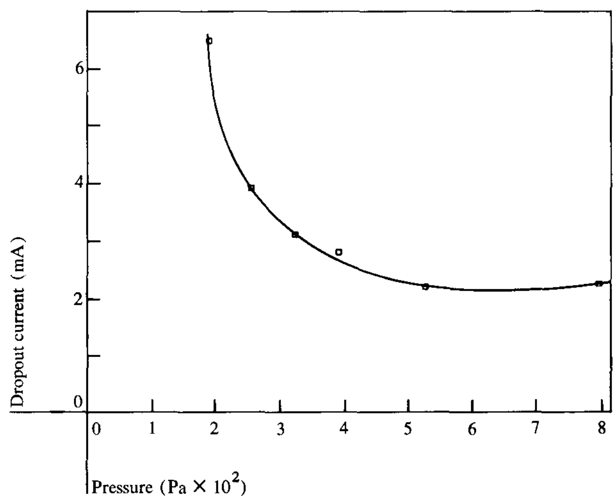

Figure 4 Dropout current as a function of pressure (from Fig. 2).

given bore diameter, d, it may be derived from an empirical relationship, $pd = 3.8 \times 10^2$ to 4.7×10^2 Pa-mm; alternatively, for any structure, optimal pressure can be determined from a set of calibration curves. To start, calibration curves similar to the ones given in Fig. 2 are necessary to establish the relationship between laser output and operating current for various pressures. These data, obtained for a 5-mW laser attached to a filling station in our laboratory, indicate that the highest power can be obtained with the lowest pressure, e.g., 2.6×10^2 Pa, but in that case the operating current is higher than 10 mA. Similar data replotted in Fig. 3 give power output as a function of pressure for different operating currents. These curves show that for an operating current of 4-6 mA, the output power is maximal if the pressure is 3.3×10^2 to 2.6×10^2 Pa. With a decrease of pressure, as can be seen in Fig. 4, the dropout current increases significantly. From the point of view of lowering the dropout current, a pressure of 4.7×10^2 to 5.3×10^2 Pa may be optimal. Furthermore, cathode sputtering tends to be slower at higher pressures and lower operating currents. Taking into account all of these factors, for this particular laser type, a pressure of 2.6×10^2 Pa and an operating current of 5-6 mA are selected as a good compromise.

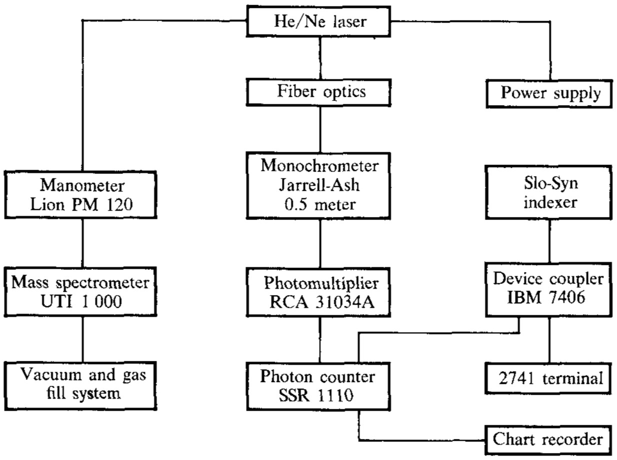

Figure 5 Systematic representation of the experimental set-up used for spectral analysis of the He-Ne lasers.

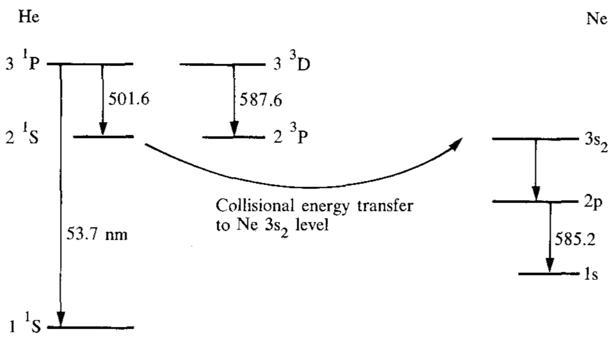

Figure 6 Energy level diagram for relevant helium and neon lines.

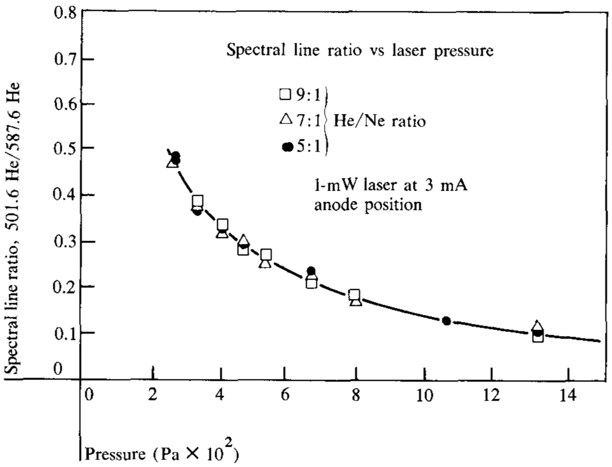

Figure 7 The ratio of the He 501.6- and 587.6-nm lines as a function of total gas pressure.

Once the laser is filled to an optimal pressure, sealed, and operated, any decrease in the total pressure with time will result in a decrease of the output power and an increase of the dropout current (following the data given in Figs. 3 and 4).

Spectral analysis

The application of spectral analysis in our laboratory for monitoring of the gas pressure in the sealed tubes is similar to that described by L. Csillag et al. [4]. The apparatus is schematically represented in Fig. 5. The method utilizes the measurement of the intensity of He lines at 501.6 and 587.6 nm and of the Ne line at 585.3 nm. The ratio of the helium green (501.6-nm) and yellow (487.6-nm) lines is strongly dependent [4] on the total gas pressure (decreasing with increases in pressure).

However, this ratio is independent of the partial pressure of neon because the electron temperature in the helium-neon laser is practically independent of the partial pressure of neon [5, 6]. The energy level diagram for the relevant emission lines is shown in Fig. 6. Both He lines have their upper energy levels excited by direct electron impact. Their electron excitation rates would be of comparable magnitude and would also have a similar dependence on the helium gas pressure, i.e., the ratio of the electron excitation rates for the 501.6-nm and the 587.6-nm lines is expected to be relatively independent of helium pressure. Further, the upper state (3 ^{3}D) for the 587.6-nm line has a single radiative decay channel which is independent of gas pressure. The upper state (3 ^{1}P) associated with the 501.6-nm transition has an alternative radiative decay scheme to the ground state by a strong resonance transition in the vacuum ultraviolet with the resulting radiation being trapped. The 3 ^{1}P state is pressure quenched by the neutral helium atoms, and this leads to a reduction in the intensity of the 501.6-nm line with increasing He pressure. Thus, the ratio of the 501.6-nm and the 587.6-nm lines decreases with total pressure of helium. The partial pressure of neon does not affect this ratio since there is no resonant energy transfer to neon from either of these two upper states of helium.

Results are given in Fig. 7 for a 1-mW commercial coaxial laser attached to a gas fill station port. The spectral measurements were made over the 13 × 10^2 Pa range for three He/Ne ratios. The ratio of the helium 501.6-nm line and the Ne 585.3-nm line, at a constant total pressure, increases with the helium to neon ratio. Data obtained for the same 1-mW laser are given in Fig. 8.

Thus, by utilizing these calibration curves, a single measurement of the three lines could provide the values of pressure and gas ratio in an uncharacterized laser. The results, shown in Fig. 7, from which the total pressure can be extrapolated, are similar in trend to results of Csillag et al. [4]. However, the data of Fig. 8 differ in trend from the relationship published by the same authors. In their work, the 501.6-nm He/585.3-nm Ne line intensity ratio increases, rather than decreases, with total pressure. This may be attributed to cataphoretic effects and a difference in the laser current/voltage characteristics. Thus, when making this type of measurement, one must specify the spatial region of the discharge that is being measured, as well as the operating characteristics.

The required calibration of the spectra of each type of laser can be obtained by using certified gas mixtures. The calibration must specify or define the discharge conditions under which it is made as well as the optical detection method employed. These measurements are sensitive to thermal variations so a laser must be allowed to stabilize before a measurement is made. The discharge current and the portion of the discharge measured, i.e., cathode or anode section, affect the calibration. These effects can be minimized if optical integration by fiber optics is used. If these details are heeded, then the three-line spectral analysis may become a reproducible method (to ±5%), useful for inspection of initial batch uniformity or timely indication of a possible failure due to cathode sputtering or gas leaks.

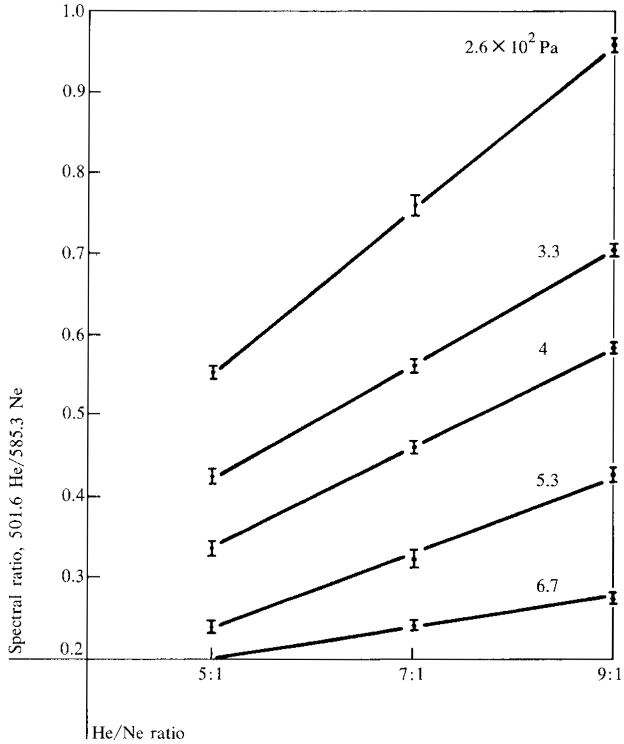

Figure 8 The ratio of 501.6-nm He/585.3-nm Ne lines as a function of the helium/neon ratio.

The dropout current is given as a minimum current at which a laser will operate, and, as often observed for gas lasers, its magnitude increases with time of operation. In order to ascertain the main factor governing this increase, one of the 1-mW lasers that had operated for a long time in our laboratory was subjected to a systematic test. From a number of variables examined, two could be singled out as being the most important: pressure and external anode to cathode capacitance. The dropout current increases as the total pressure decreases. The curve, similar to the one given in Fig. 4 obtained for the 1-mW unit, was used as an alternative, useful tool for pressure measurement of other lasers of the same kind. Results obtained on a number of these lasers using this technique compare well with pressure values deduced from spectral analysis. However, we felt that this should be further evaluated to understand the effects of variations in laser geometry and gas mixture before being utilized as a standard method for pressure evaluation.

Summary

Measurements of drop-out current and emission spectroscopy have been used for nondestructive evaluation of gas pressure, purity, and He/Ne ratio in sealed helium-neon lasers. With proper calibration, the measurement of three spectral lines (He, 501.6 nm and 487.5 nm, and Ne, 585.2 nm) allows the evaluation of both total pressure and the He/Ne ratio. These nondestructive methods have proved themselves very useful in the evaluation of the impurity level, total pressure, and helium/neon ratio during our parallel plate laser program.

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