

HE-NE OPTICAL MASERS: CONSTRUCTION AND MEASUREMENTS

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The construction and the operation of the gas lasers built at C.I.S.E. Laboratories are described. A detailed analysis of all the technological problems arising during the construction is given.

Thermal and frequency measurements are reported. The laser power output and the number of oscillating modes increase with the temperature at a constant discharge power. Evidence for this new effect, which is peculiar of a sealed-off container, is given by the experimental curves.

I. - INTRODUCTION.

We have built and operated some continuous He-Ne lasers, both with r.f. and d.c. discharge excitation, and for I.R. transitions.

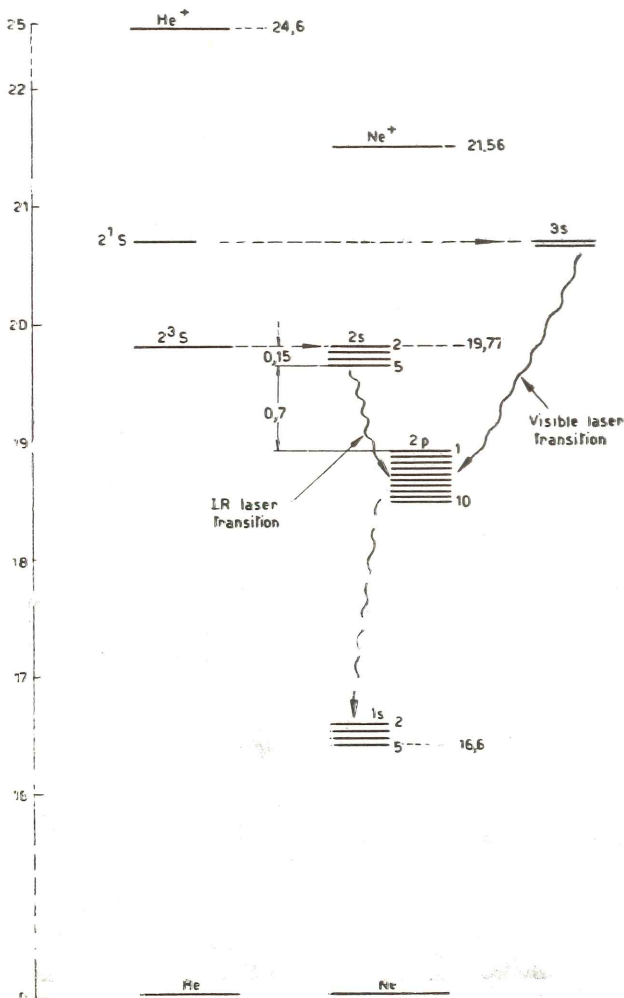


Fig. 1. — Energy level diagram of the He-Ne system

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The results already given in the literature are briefly summarized, before describing the technical features of our device and reporting the performed measurements.

We refer to a longer review article for further information on the physics of the gas laser operation [1].

The first gaseous laser has been proposed by Javan [2] and then operated by Javan et al. [3]. It consisted of an r.f. discharge tube containing a mixture of helium and neon, with optical feedback provided by high-reflectance flat mirrors inside of the vacuum envelope. Oscillations were observed at five wavelengths in the near infrared, the strongest occurring at 11530 Å. These oscillations correspond to some of the 30 possible transitions from the 2s to the 2p states of the Ne atom. The excitation of the Ne (2s) states is due to resonant transfer from the He (2^3S) metastable state generated by the r.f. excitation (fig. 1).

A new type of e.m. cavity has been successfully used by Rigrod et al. [4]. They used concave mirrors at a distance equal to the radius of curvature (confocal geometry) [5]. The mirrors were placed outside of the gas-discharge tube, the ends of the tube were made by optically flat windows oriented at the Brewster angle to the beam axis, in order to minimize reflection losses for radiation polarized in the plane of incidence.

Three further contributions must be mentioned in connection with the He-Ne gas laser.

The first is the use of the off confocal geometry [6] (distance between mirrors different from the radius of curvature) for removing the e.m. modes degeneracy.

The second is the laser action on a visible wavelength (6328 Å) [7] based on a level scheme similar to the one used in the I.R. The laser transitions in Ne occur from the 3s to the 2p levels, and the 3s levels are excited by resonant transfer from the He (2^1S) state.

The third, used in connection with the visible gas laser, is the use of a d. c. discharge instead of the r.f. one.

2. - TECHNICAL PROBLEMS INVOLVED IN THE CONSTRUCTION AND OPERATION OF THE LASERS.

2.1. - The e.m. cavity.

We have used the near confocal geometry for our e.m. cavity. The advantages over the plane geometry are given in Ref [4].

The end mirrors are quartz discs with 3,2 cm diameter. The radius of curvature of the inner surface is 100 cm and this surface was worked better than 1/20 of λ_D for the first pair of mirrors. For the next ones the accuracy was reduced down to $\frac{1}{4} \lambda_D$ and we believe that even less than this can be accepted (1).

The curvature of the outer surface is such that the spherical wavefront coming out from the laser cavity

(1) If we compare the 24 minutes of arc half-width of the power versus misalignment curve for confocal laser [4] with the the 1 second half-width for plane laser [8], and we assume that the scattering action of the irregularities acts on the cavity as the lack of parallelism, a $15\lambda_D$ accuracy should be the confocal correspondent to the $1/70 \lambda_D$ accuracy for plane mirrors.

is converted into a plane wave for the useful wavelength (11530 Å).

The reflecting surface is made of multiple layers dielectric coating. The usual techniques of alternating ZnS and Mg F₂ layers has been used.

The wanted reflectance is reached for 13 layers [9].

The transmittance curve recorded by a spectrophotometer Optica CF4NI is shown in fig. 2.

In order to avoid strains in the flat windows they were joined to the tube by an epoxy vacuum-tight seal. This seal required a rather low temperature (180° C). This way a high temperature baking could not be used, and a getter was required to keep the gas clean from impurities.

On a long time test there is no reason to prefer fused silica to pyrex. The velocities of diffusion of the atoms

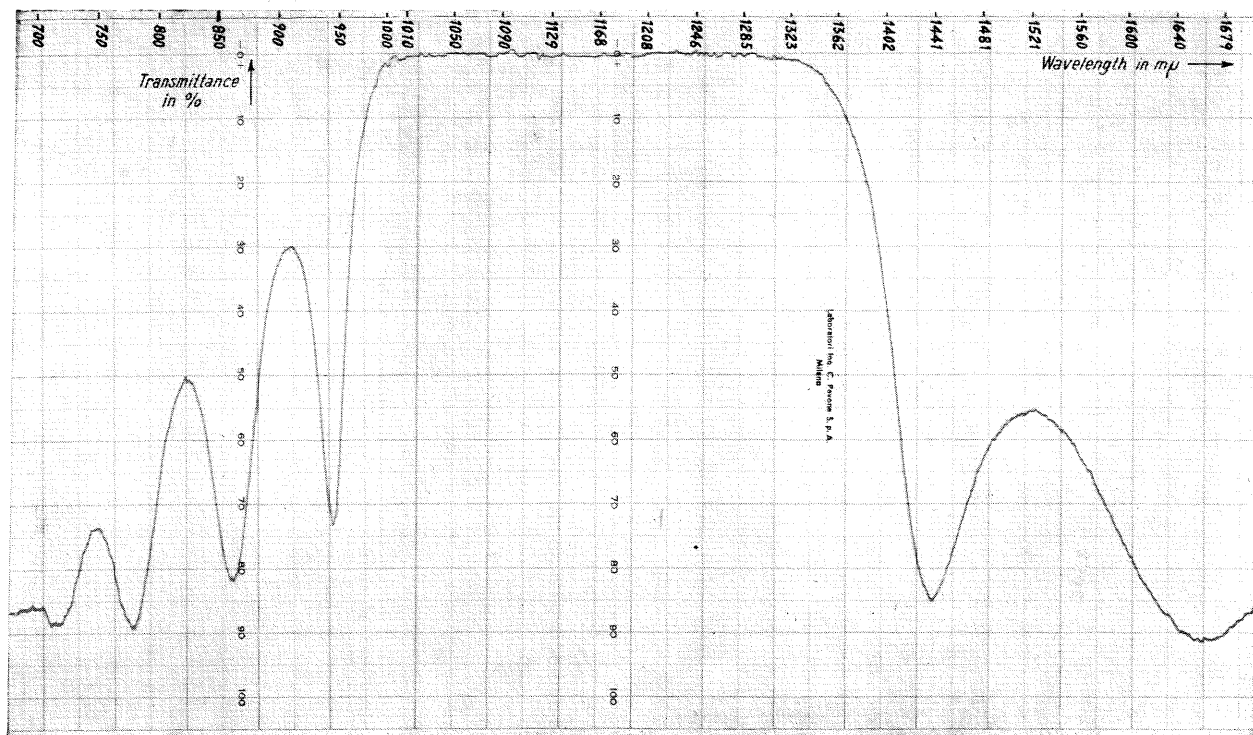


Fig. 2. — Transmittance versus wavelength of a 13 layers dielectric coating

The reflectance used in the first He-Ne laser (see Ref. [9]) was 98.9% ± 0.2% at the peak, against a transmittance of 0.3%. The 0.8% difference corresponds to a scattering and absorption loss. For dielectric layers, the absorption can be considered negligible in comparison with the scattering action of the evaporated crystals over the photons of the lasing modes. In order to avoid the formation of large crystals, the ZnS layers were evaporated at a rate of about 300 Å/minute [10].

2.2. - The active medium.

The active medium is a mixture of He and Ne gases of spectral purity in the ratio 10:1.

We have filled three different containers having the following characteristics:

| Material | Discharge | Total pressure (mm of Hg) | Inner diameter (cm) | Length (cm) |
|--------------|-----------|---------------------------|---------------------|-------------|
| Fused silica | r.f. | 1.1 | 1.1 | 96 |
| Pyrex | r.f. | 0.7 | 0.7 | 94 |
| Pyrex | d.c. | 0.7 | 0.7 | 94 |

The ends of the container were closed by optical flats at the Brewster angle to the beam axis.

through these glasses are almost the same [11], and eventual impurities degassing from pyrex can be adsorbed by the getter.

In the case of the r.f. discharge the supply is a conventional 100 W, 30 Mc/s oscillator coupled to the discharge tube through a matching coil to external electrodes (fig. 3).

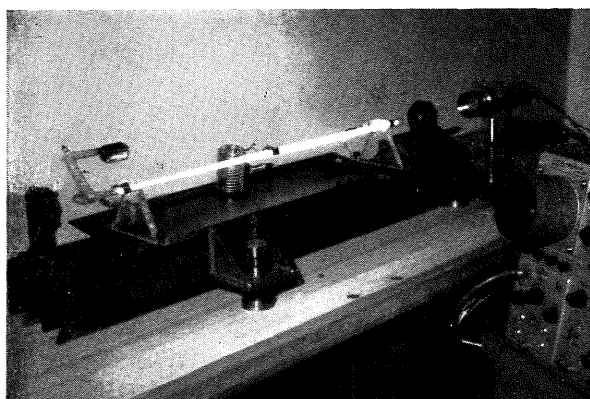


Fig. 3. — Photograph of the r.f. discharge laser

When d.c. operated the discharge requires from 15 mA on, with a voltage fall ranging in the 1700 v region.

In the d.c. discharging the ions impinging on the cathode cause metal sputtering on the walls. The metal layer

seems to adsorb Ne, because after some time the discharge turns from the Ne to the He colour and the laser action stops.

If the discharge current is supplied by a tungsten thermionic cathode [7], the cathode fall (and therefore the energy of the impinging ion) will be lowered.

A first test with a thermionic cathode having a saturation current less than the discharge current has shown that the sputtering phenomenon is reduced but not eliminated.

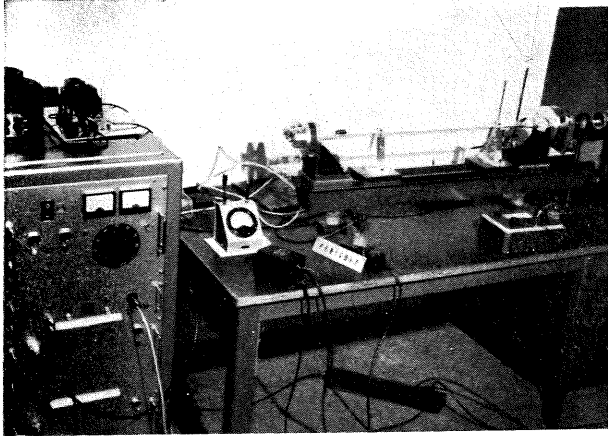


Fig. 4. - Photograph of the d.c. discharge laser.

An improved cathode able to supply all the discharge current has lowered the sputtering rate to a negligible amount. The d.c. set up is shown in fig. 4. Fig. 5 gives the schematic diagrams in the two cases.

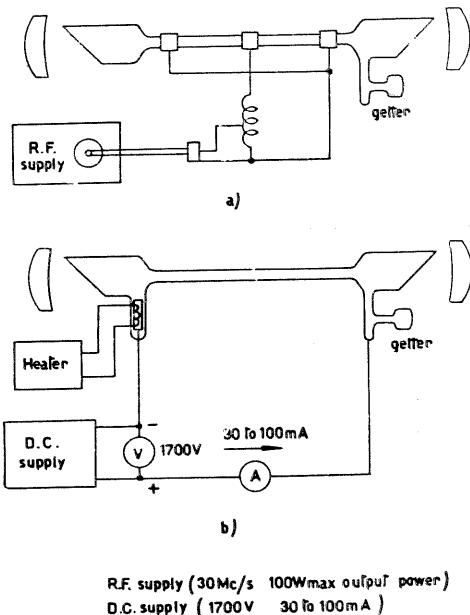


Fig. 5. — Schematic diagram of the r.f. and d.c. lasers

2.3. - Optical alignment.

The alignment of the mirrors was performed in the confocal position.

A screen with a central pinhole is placed at one mirror and illuminated in the back by a bright source. The pinhole acts as a point source and the image reflected from the other mirror is focused back on the screen and adjusted to coincide with the pinhole. The system gives a 20 seconds of arc resolution.

When the gas container is inserted between the mirrors the alignment has to be slightly re-adjusted. This misalignment can be explained by a small lack of parallelism between the two faces of each Brewster window, which acts as a prism with a 3 minutes of arc angle.

3. - MEASUREMENTS.

First we made quite straightforward checks as:

a) polarization of the E vector in the plane defined by the beam axis and the normal to the Brewster plate.

b) beam lobe width, by moving a phototube, with a narrow hole in front of the photocathode, along or transversally to the beam axis.

c) gain and losses in the optical path by introducing an optical flat between a Brewster window and the near mirror, and then tilting the flat from the Brewster angle up to the position normal to the beam axis and observing the reduction in the laser output down to the complete extinction.

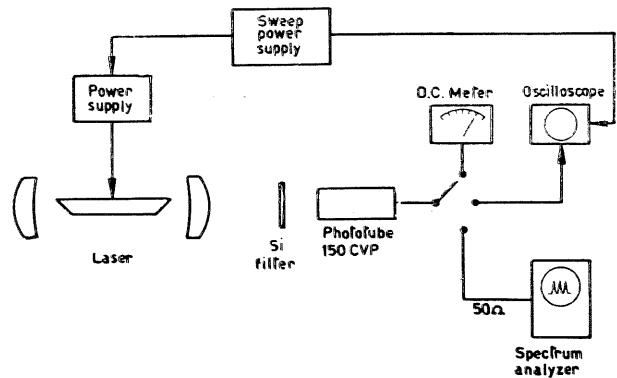


Fig. 6. — Experimental set up for the measurements

We made then some output power measurements and we found a thermal effect not described elsewhere. The output power of a laser with a sealed off gas container is a function not only of the discharge power, but also of the temperature [12]. We have made three series of curves:

a) laser output versus temperature at a constant discharge power (fig. 7 a).

b) laser output versus discharge power at a constant temperature (fig. 7 b) (this plot actually represents the «short time» behaviour, because, due to the heating effect of the discharge, the temperature rises up from the standard 300 °K value with a thermal transient having a time constant of about 200 sec and all the experimental points were taken in a time short compared with this time constant).

c) laser output versus power with each point at the temperature of equilibrium between heat generation and dissipation (fig. 7 b). (This plot represents the «long time» behaviour; the measurements for each point were made after the thermal transient). The discharge temperature was tested with some Chromel-Alumel thermocouples distributed along the discharge length. We notice that at a constant temperature the laser output power has a maximum for a certain value of the discharge power.

We measured then the frequency of the beatings between the different longitudinal modes excited in the e.m. cavity. The beam was collected on the photocathode of a 150 CVP photomultiplier. The output of this tube was connected to a Polarad spectrum analyzer

and beat signals were observed around 160 Mc/s. At low temperature only one peak was present in that frequency region, while at increased temperature the pattern showed two or more peaks with the same disch-

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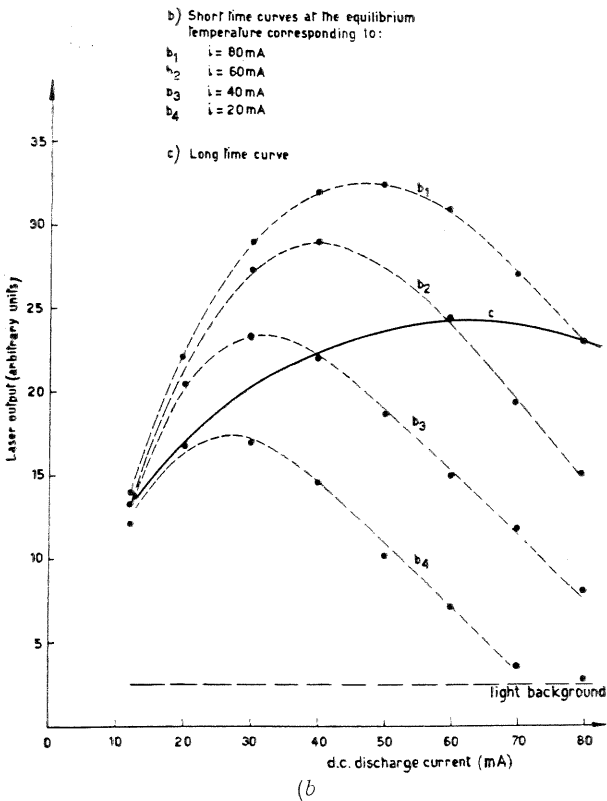
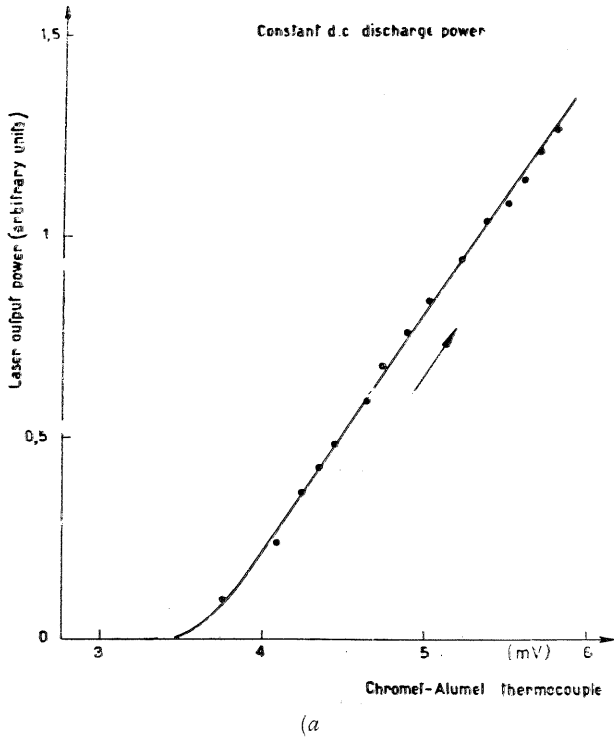


Fig. 7. — Plot of the laser output versus discharge current for «long time» and «short time» operating conditions

arge power (fig. 8 a and 8 b). This can be explained by a Doppler broadening of the atomic transition line and a frequency pulling effect [13] on the longitudinal modes.

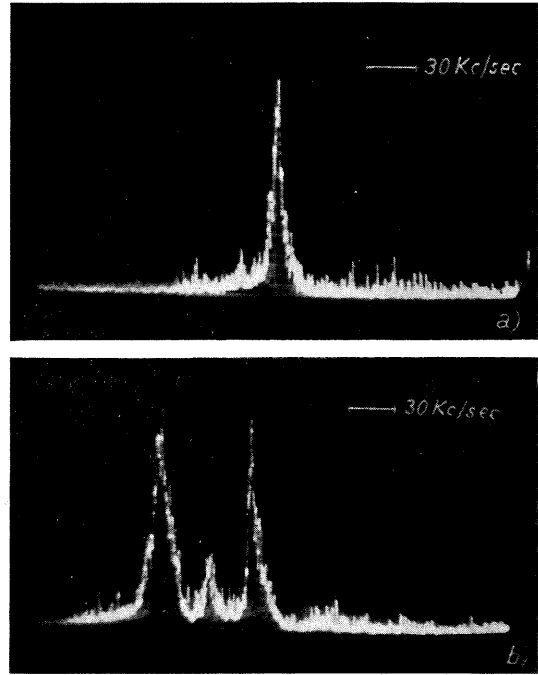


Fig. 8. — Photographs of the r.f. beats between modes of the gas laser

flecting coating on the mirrors, the «Tecniche Sperimentali» group of CISE for making and filling the pyrex containers both for the d.c. and the r.f. discharge systems.

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