I-2. MEASUREMENTS ON A THERMAL GRADIENT GAS LENS

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A thermal gradient gas lens (References 1,2,3) has been investigated experimentally for a variety of conditions and gases. The results in general show good agreement with the theory and indicate that these lenses may be useful in long distance optical transmission lines.

The lenses investigated were 0.250 inch diameter heated metal tubes through which a cool gas was blown. The temperature distribution assumed by the gas as it flows through the tube and the resultant density gradients in the gas create a positive optical lens. The lens has no surface with an abrupt index discontinuity as do conventional glass lenses and hence has very small reflectivity and scattering losses.

As the first step in determining the properties of these lenses, the temperature distribution inside the lens was probed with a small thermocouple. The profiles were measured for several wall temperatures, several gas flow rates, and for CO_2 and N_2 gases. Except for the convection effect of gravity, which is not included in the theory, the temperature distributions were found to agree quite well with the theory.

Figure 1 shows the measured temperature distributions when the effect of gravity is strong. These were taken with a 1 liter/min flow of CO_2 gas with an input temperature of 25.8°C and a tube wall temperature of 100°C. These profiles were taken in the vertical plane of a tube whose axis was horizontal. Gravity causes the distribution to be asymmetrical with the coldest point being below the center of the tube. Crossections taken in the horizontal plane are symmetrical.

The theoretical distributions are shown as dashed curves in Figure 1. These curves should be symmetrical about the center of the tube but have been displaced so their centers agree with the measured data. It can be seen that convection has the effect of displacing the center of the distribution downward but near the center of the distribution it still has the same shape as predicted by theory. Near the walls the shape of the profile does not agree with theory. The effect of this asymmetry on the optical properties of the lens will be shown later.

For other gases, flow rates, or wall temperatures it is possible to reduce the convection asymmetry in the temperature profiles. However, if one wishes a given focal length lens it is not known if there is a desired combination of gas, flow rate and wall temperature which will give a minimum convection asymmetry.

The optical properties of these lenses were investigated with a lateral shear interferometer illuminated with laser light at 6328Å. The interferometer is shown in Figure 2. From a photograph of the interference patterns the focal length and aberrations of the lenses can be measured.

Figure 3 shows the construction of the gas lens used in the optical measurements. To keep the gas flow laminar, a porous tube was used to introduce the gas into the lens.

A comparison between the measured and predicted focal distance for a 100°C wall temperature is shown in Figure 4. The focal distance is measured from the gas exit end of the heated tube to the focal point. The agreement with theory is good.

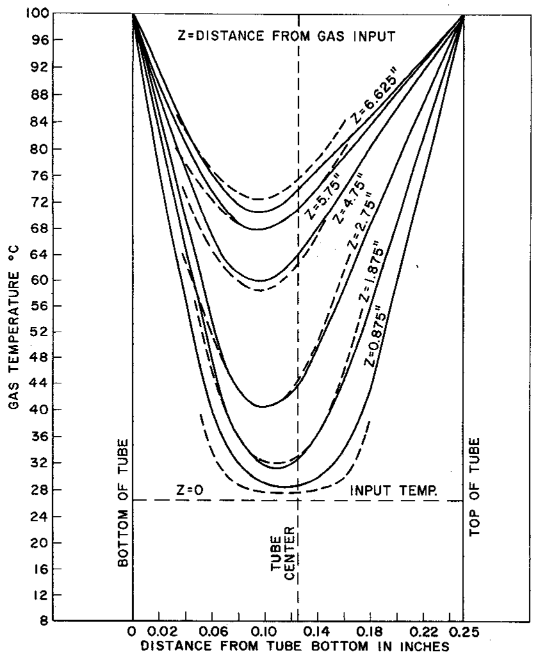

Figure 1. Vertical Temperature Profiles for CO_2 1 Lit/Min, 100°C Wall

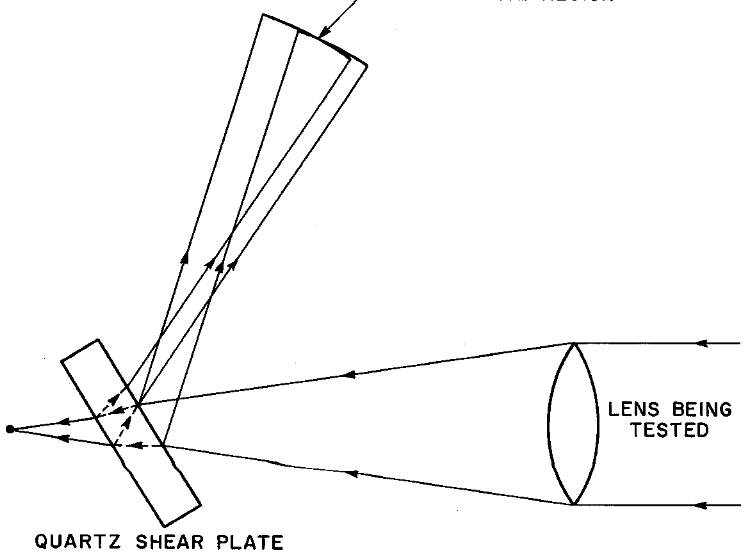

Figure 2. Lateral Shear Plate Interferometer

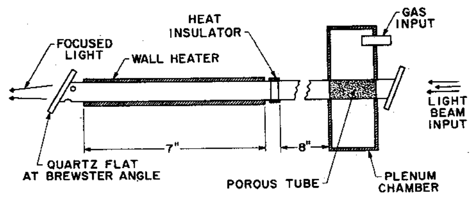

Figure 3. Experimental Gas Lens

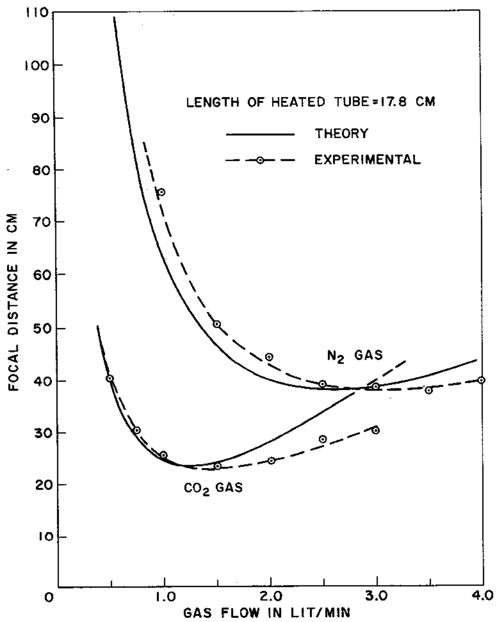

Figure 4. Focal Length versus Gas Flow Rate, 100°C Wall Temperature
23.3°C Gas Input Temperature

This data and that taken at other wall temperatures show a discrepancy in focal distance at high flow rates. Also the lens aberrations predicted at high flow rates were not observed. However, a check of the temperature distribution inside the tube at high gas flow shows good agreement with theory. The cause for the observed discrepancy in optical properties has not been determined.

The aberrations observed in the experiments can be attributed to gravity. Gravity causes the temperature profiles to be displaced downward and hence to first order causes the focal length to vary across a vertical tube diameter as

$$f(x) = f_o \left| 1 + \alpha (x + \Delta) \right| ,$$

where

x = vertical distance from the center of the tube

α, Δ, f_o = constants depending on the gas used, flow rate, and wall temperature.

The focal length was found to be constant within the accuracy of the experiment across a horizontal tube diameter. The effect of gravity is therefore to make the equivalent glass lens have a tear shaped vertical crossection as shown in Figure 5.

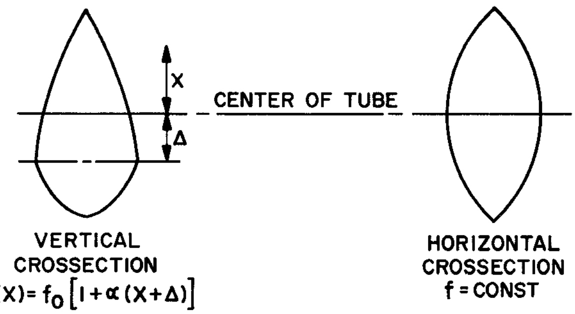

Figure 5. Equivalent Glass Lens for a Gas Lens with Convection

Since a flowing gas is used in these lenses it was questioned if the focusing action would remain stable in time. The stability was checked using a Mach-Zehnder interferometer. The interference patterns obtained were very stable in time, indicating good stability in the lens.

Judging from the measurements made thus far on the gas lens it appears to have good potential in long distance optical communication systems. For example a lens with a 50 cm focal length with small convection aberrations is possible using nitrogen. A series of these 0.25 inch diameter lenses spaced at 50 cm would give an optical transmission line with the following properties at 6328Å:

Beam spot radius = 0.33 mm

Minimum bending radius of the line for 0.33 mm beam deflection = 1500 meters.

Since the diffraction losses of such a line would be extremely small, the losses will primarily be determined by the scattering from the gas, imperfections in the lenses, and misalignment of the lenses. It would seem that these losses could be kept low.

REFERENCES

1. Marcuse, D., "Theory of a Thermal Gradient Gas Lens," see previous paper.

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4. Marcuse, D., "Propagation of Light Rays through a Lens-Waveguide with Curved Axis," BSTJ, Vol. 43, March 1964, pp. 741-754.