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Fresnel Lens Characterization for Potential Use in an Unpiloted Atmospheric Vehicle DIAL Receiver System

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1. Introduction

Fresnel lenses are nonimaging lenses that are lightweight and inexpensive. Such lenses are made of plastic material and are easily replaceable. One application for such a lens is in the optical receiver of an Unpiloted Atmospheric Vehicle (UAV). The Fresnel lens could serve as both the optical window and the light-focusing element. Figure 1 shows a side view of a typical UAV water vapor DIAL (differential absorption lidar) system. Atmospheric light returned at 820 nm enters the window/Fresnel lens which focuses the light onto the turning mirror which then focuses the light onto a fiber-optic cable. The cable transmits the light to an avalanche photodiode detector (APD) and the output is then digitized and stored.

The Fresnel lens is inexpensive ($70) enough that it is easily replaceable if it became scratched and can be manufactured in large diameters and in various shapes (i.e., circular, rectangular). The main drawback is the poor focusing quality. The goal of this research effort is to characterize the size of the focal spot as a function of wavelength. Also, we are concerned about the optical transmission properties of the lens. This research effort characterizes these lens for future DIAL receiver system designers.

2. Experimental Setup

The results presented here were taken with a circular Fresnel lens made of arcylic plastic with a diameter of 30.5 cm (12 in.) and focal length of 61 cm (24 in.) The lens was illuminated with a collimated mercury continuous-wave (Hg cw) light beam, and its focal characteristics were measured with a beam profiler. The spectral transmission was measured with a photodiode in the beam path while the lens was alternately put in and out of the beam path. The beam wavelength was set by inserting various interference filters at the output of the lamp source.

The experimental setup shown in figure 2 consists of a Hg cw lamp source, a beam expander, and iris and filter assembly. The Fresnel lens was set on a holder, and a CCD camera of the beam profiler system (BeamPro$_{\text{filer}}$ from Photon Inc.) was set on a rail so that it could be moved in the z direction. The beam expander collimates the beam that illuminates the lens; thus a sharp spot is created at the focal point of the lens. The beam collimation was checked by measuring the beam diameter over a distance of 9 to 10 m and by setting it approximately equal over this distance. The iris was set to an opening that will illuminate the lens full diameter, and the filters were used to set the measurement wavelength and to limit the spectral bandwidth to about 10 nm.

3. Measurements, Results, and Analysis

The lens characterization consisted of the following measurements:

Focal spot intensity profile: Figures 3 to 6 show typical focal spot intensity profiles for 750, 800, 850, and 910 nm as taken from the beam profiler. The CCD camera was moved in the z direction until the minimum spot size was achieved. As seen from the figures, the beam at the focus does not have any regular shape or symmetry and it does not fit any regular category (Gaussian, elliptical, or flat top). The elongation seen may be caused by the off-axis illumination of the collimating mirror. The CCD camera had a sensor size of 6.4 by 4.8 mm and a pixel spacing of 8.4 (H) by 9.8 μm (V). The size of figures 3 to 6 corresponds to the full CCD sensor dimensions. The spot size in terms of full-width-half-maximum (FWHM) was about 1.1 to 1.6 mm whereas the $1/e^2$ diameter, which includes 86.5percent of the total power, was on the order of 5 mm. The intensity profile at 910 nm was low because of the low Hg arc lamp optical output in this spectral region.

Variation of spot diameter with deviation from focal point: From the analysis of the beam profiler, the FWHM size was plotted for different wavelengths as a function of the camera position z, near the focus. In these photographs the minus sign indicates distance toward the collimating mirror. The measurements, calculated by the beam profiler software, have 10 to 15 percent error, even after calibration, especially when moving out of the focal point where the signal was too small to use the full dynamic range of the sensor. These graphs show that a small difference exists in the vertical and horizontal FWHM size, but this difference is minimal at the lens focus.

The focal length change as a function of wavelength from 750 to 910 nm was observed to be very small—less than 2 mm and mostly within the measurement error. The changes of the FWHM focal point size were more observable and are shown in figure 11 for the wavelength range of 750 to 910 nm.

For a 32.7-cm-diameter lens, the diffraction limit is on the order of 2 μm. The performance of the Fresnel lens was obviously low, on the order of 2000 times diffraction limit (4 mm) for a $1/e^2$ diameter. This result gives an indication of the detector size needed to capture the focused radiation.

Lens spectral transmission: A critical factor in the use of these lenses is the spectral transmission at the wavelengths of interest. Because this lens is acrylic plastic, it should have the best transmission in the visible region. The spectral transmission of the uncoated lens was high at about 0.8 and quite flat in the spectral range as shown in figure 12, which was close to the manufacturer's specification of 0.85.

Effects of bending and heating lens: Bending disturbance was done by having one side of the lens firmly held while the other side was pushed as far as 5 mm from the straight position. The minus sign indicates bending towards the collimating mirror. This bending deforms the lens surface to a curve with an approximate angle of 15 mrad. Heating was done by placing a heat gun at a distance of ≈30 cm from the lens. The heat gun was operated for about 2 min; this resulted in a lens temperature increase of a few °C.

Qualitative measurements of bending and heating influences on the focusing characteristics show an estimated 10- to 20-percent change in the focus spot size and the intensity distribution because of these imposed disturbances as shown in figures 13 to 16. Also it was observed that by removing the disturbance, the lens returned to the original position as seen when comparing figures 13 and 15.

4. Concluding Remarks

The Fresnel lens tested had a large focal spot when compared with a diffraction limited lens of the same dimension. The focus spot shape was an irregular pattern not easily described by a Gaussian profile. For our lens, the focal point size varied from 1.2 mm at 750 nm to 1.6 mm at 910 nm. These measurements give an indication of the detector size needed to capture all the focused radiation.

The uncoated lens had 80 percent transmission over the wavelength interval of 750 to 910 nm. This transmission is adequate for the water vapor DIAL wavelengths of interest and is comparable with the manufacturer's transmission specification of 85 percent.

The use of this lens in a UAV will require attention to vibration and heating effects. We have preliminary qualitative measurements of bending and heating the lens and found about a 20-percent increase in the focal point size. When heating or bending was removed, the lens returned to its original FWHM focal spot size.

It would be worthwhile to check the possibility of using this lens in conjunction with a tapered fiber-optic or some other form of optical nonimaging condensator that could more efficiently collect the light at the focal point and deliver it to a smaller diameter APD detector.

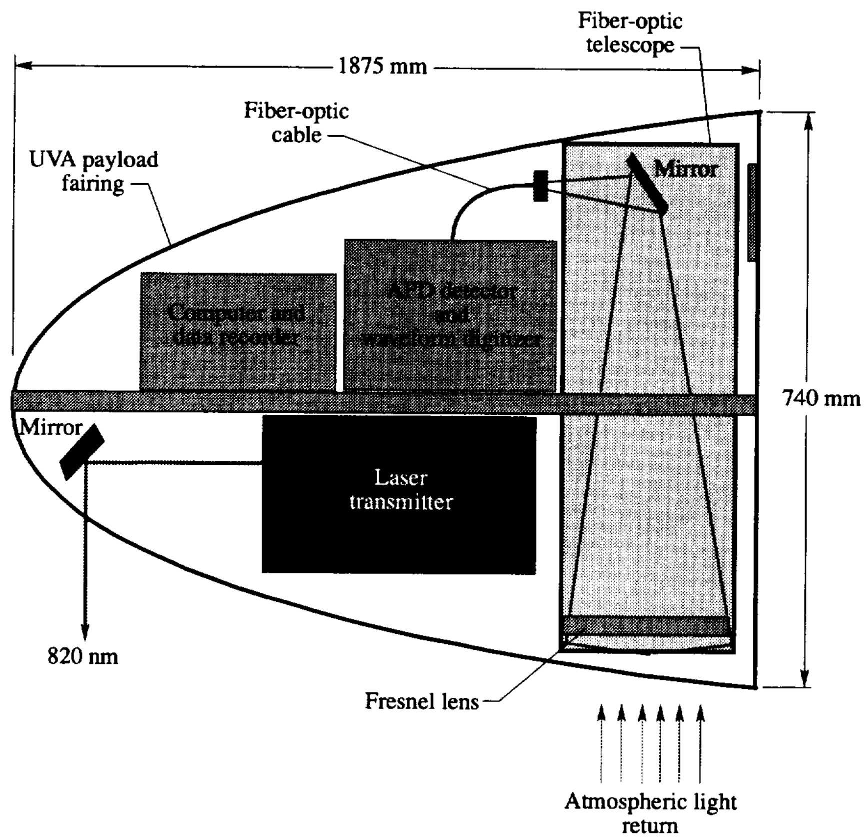

Figure 1. Side view of UAV payload compartment.

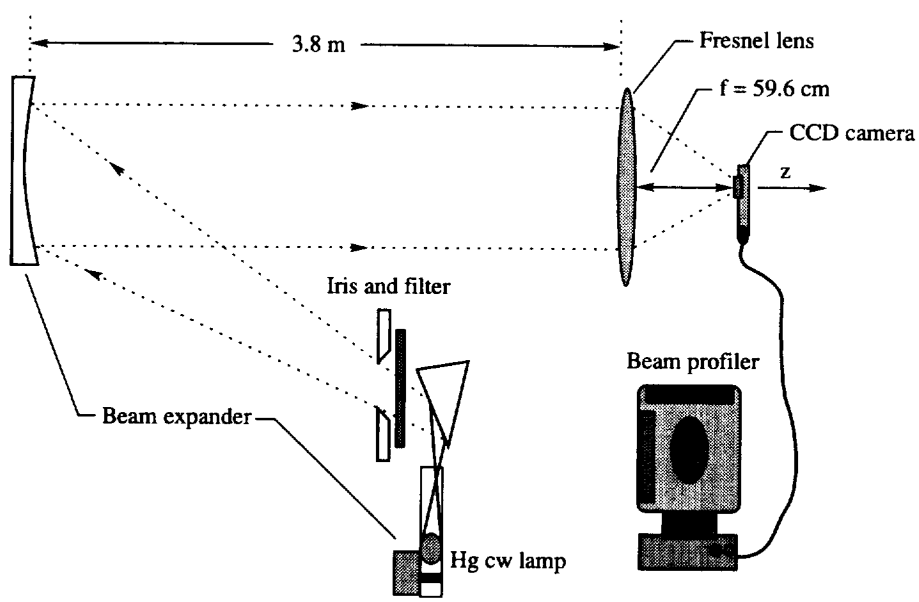

Figure 2. Experimental setup.

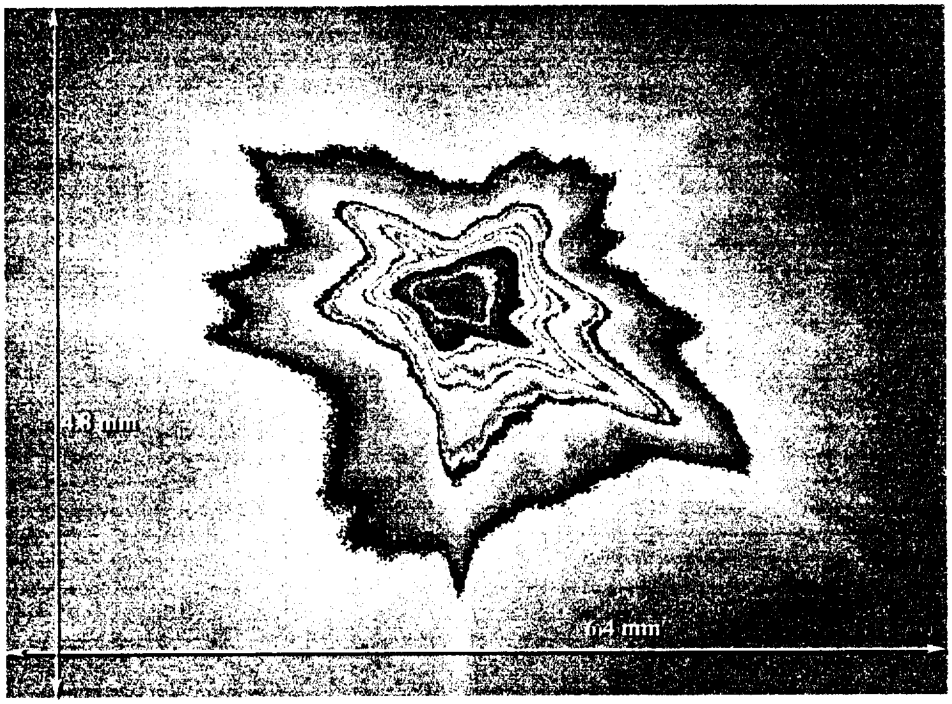

Figure 3. Beam spot at focal point at 750 nm.

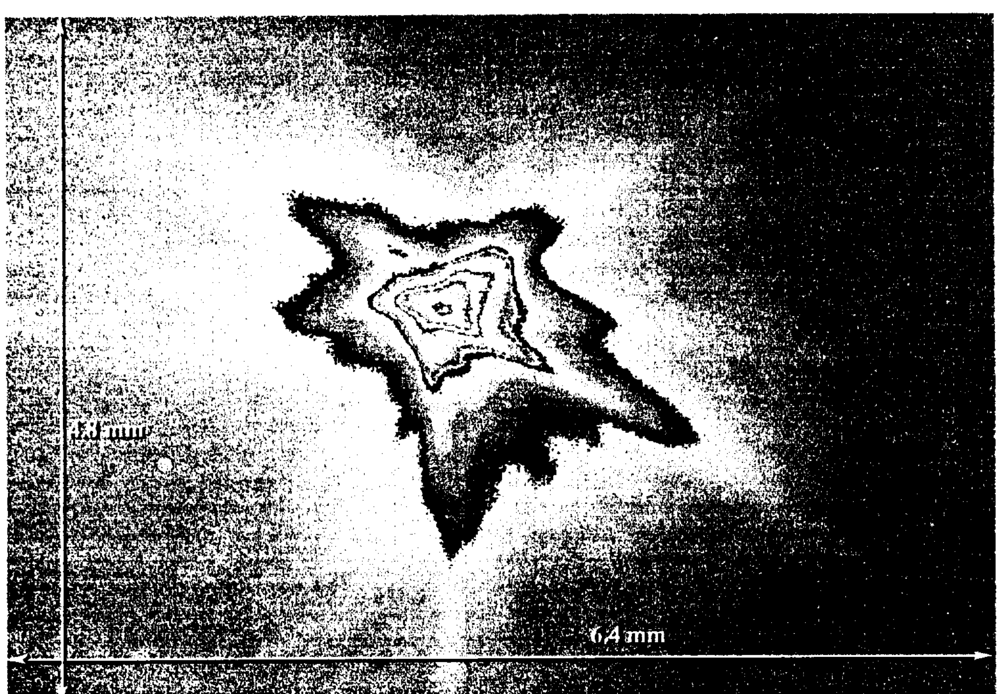

Figure 4. Beam spot at focal point at 800 nm.

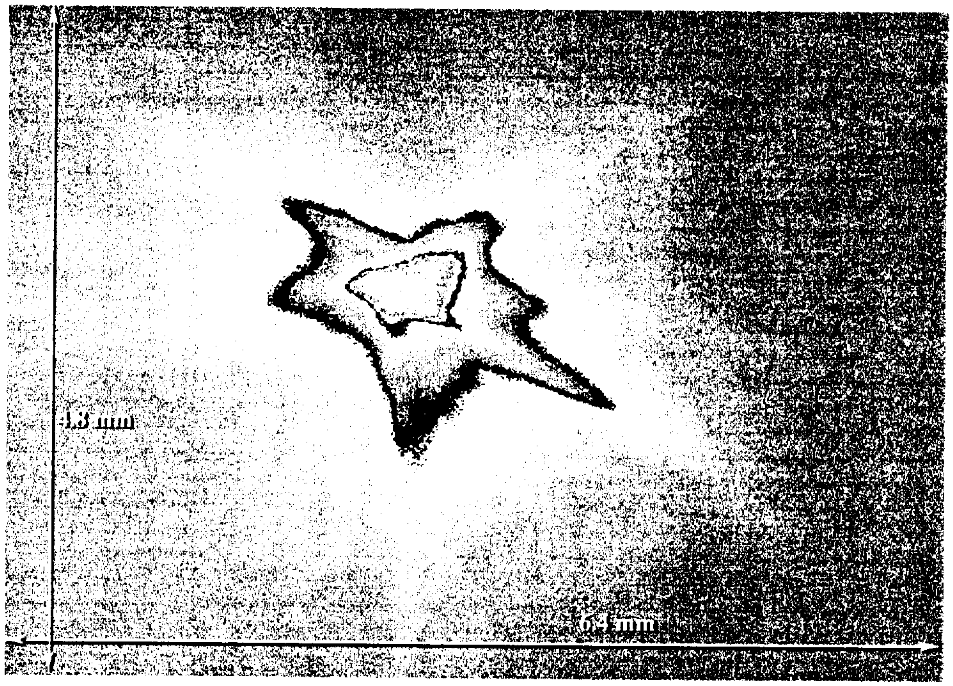

Figure 5. Beam spot at focal point at 850 nm.

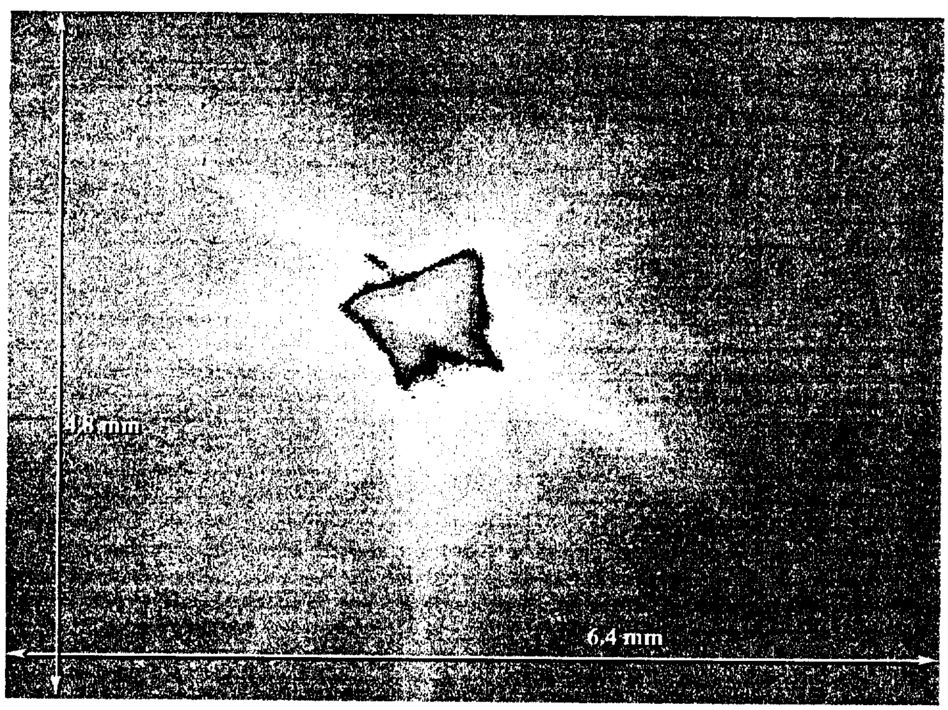

Figure 6. Beam at focal point at 910 nm.

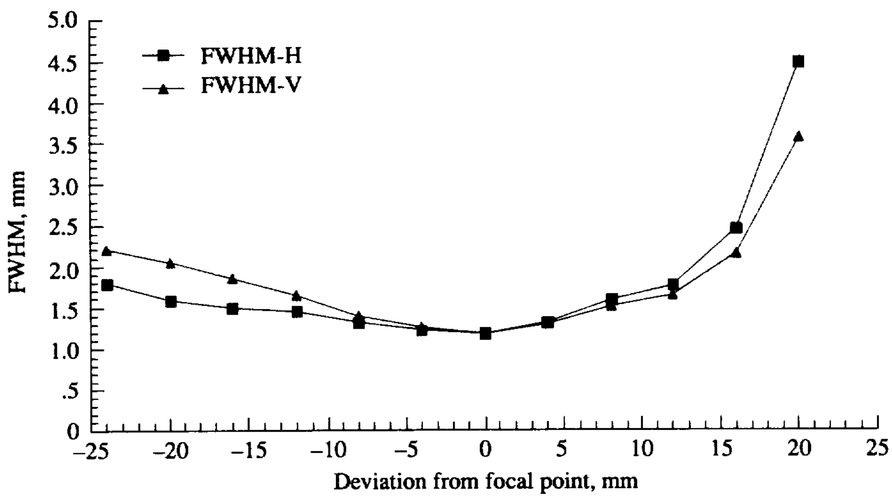

Figure 7. FWHM as function of position near focal point at 750 nm. f = 596 mm.

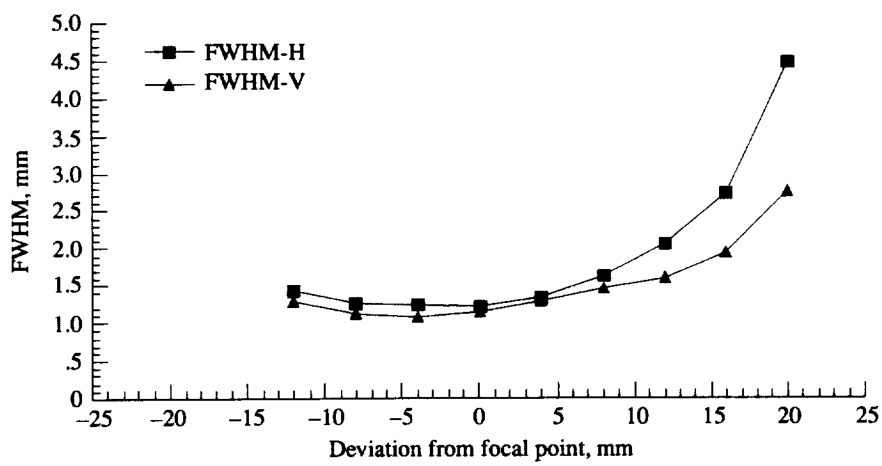

Figure 8. FWHM as function of position near focal point at 800 nm. f = 596 mm.

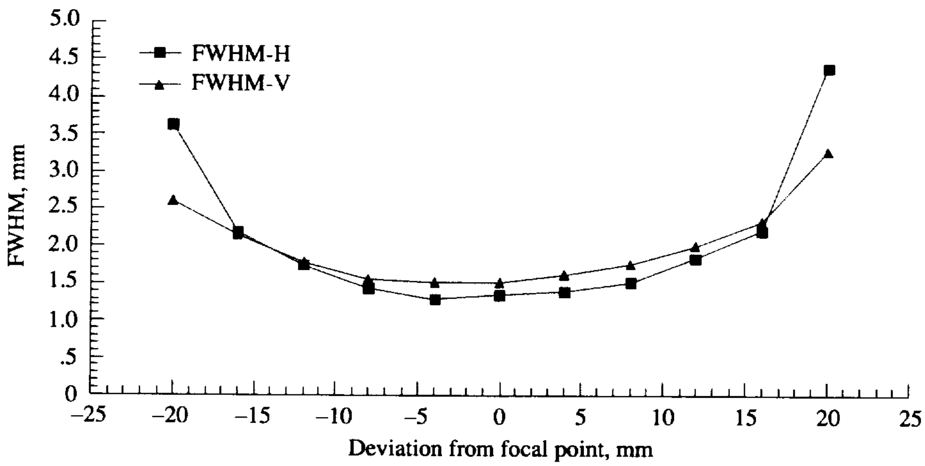

Figure 9. FWHM as function of position near focal point at 850 nm. f = 596 mm.

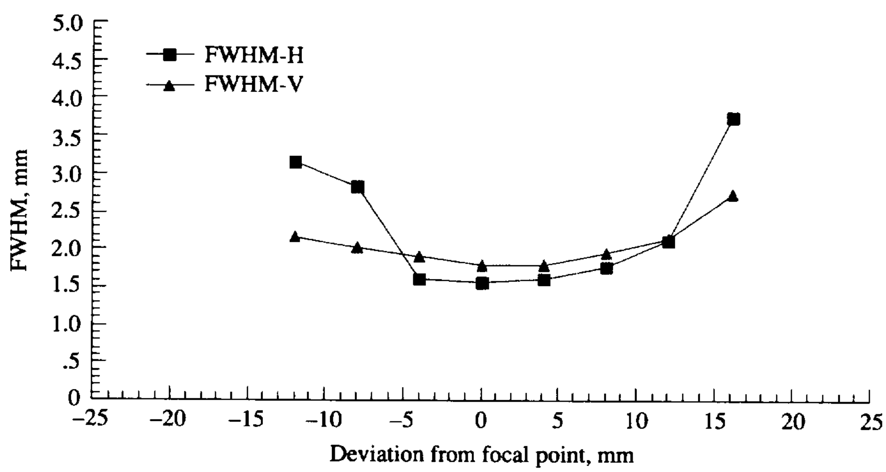

Figure 10. FWHM as function of position near focal point at 910 nm. f = 596 mm.

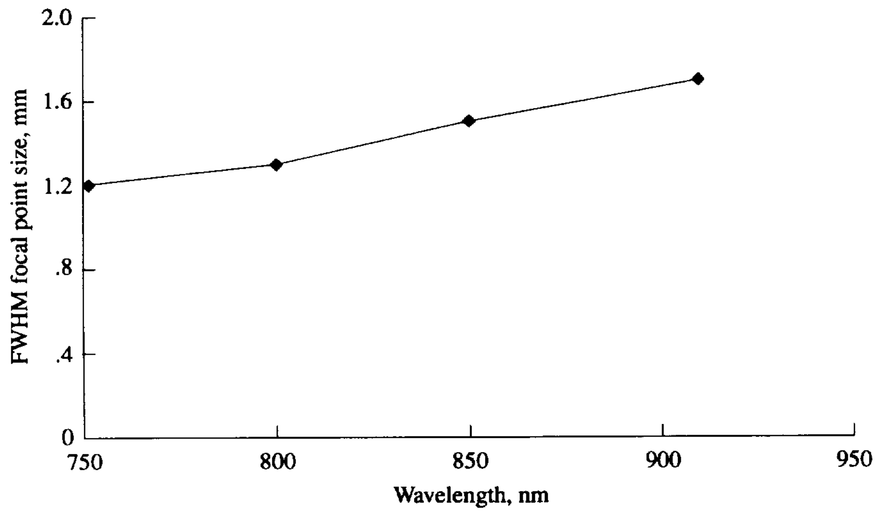

Figure 11. FWHM focal point size as function of wavelength.

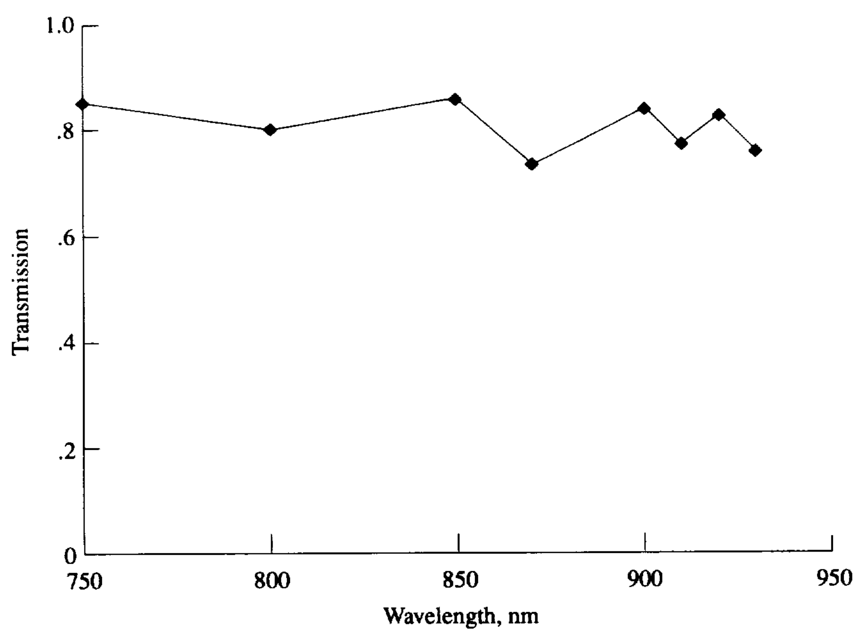

Figure 12. Lens transmission as function of wavelength.

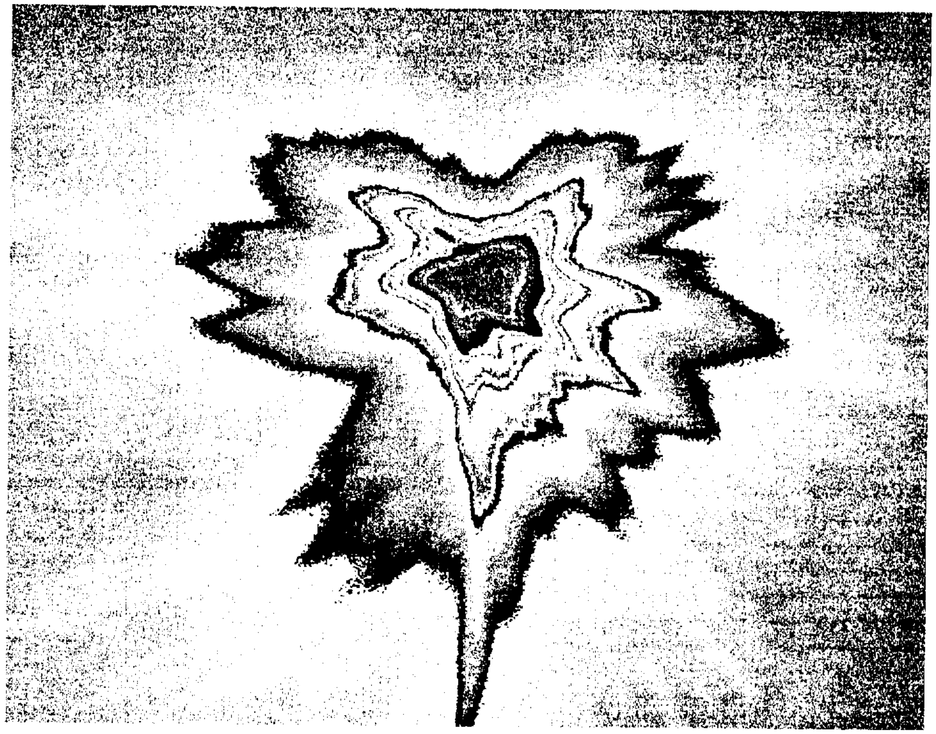

Figure 13. Unperturbated room temperature beam spot at focal point at 750 nm.

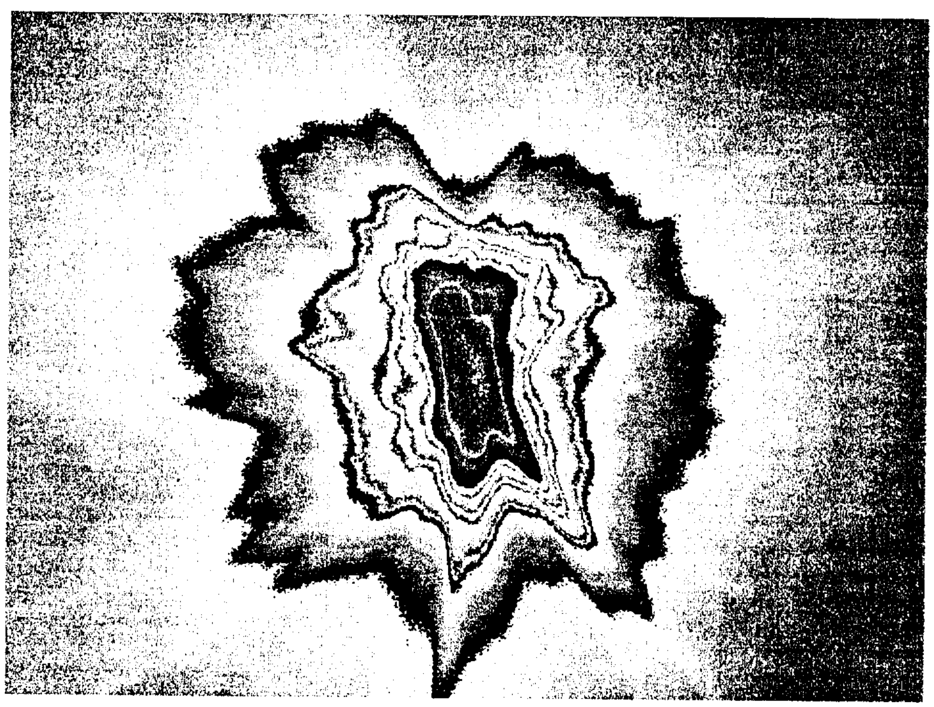

Figure 14. Same beam as figure 12 with horizontal bend of ≈5 mm.

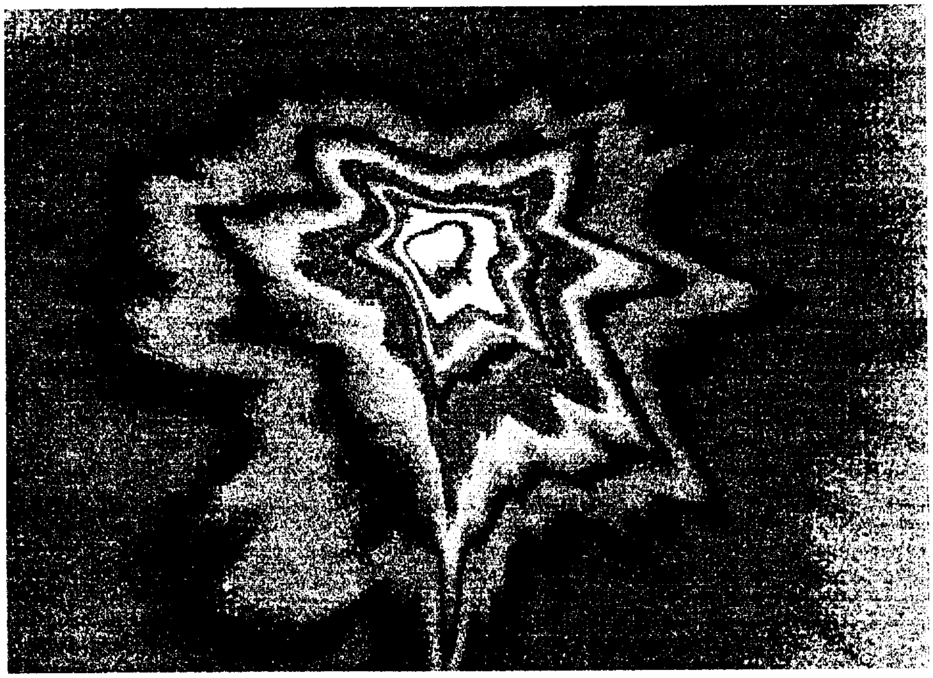

Figure 15. Beam spot at focal point after heating for 2 min.

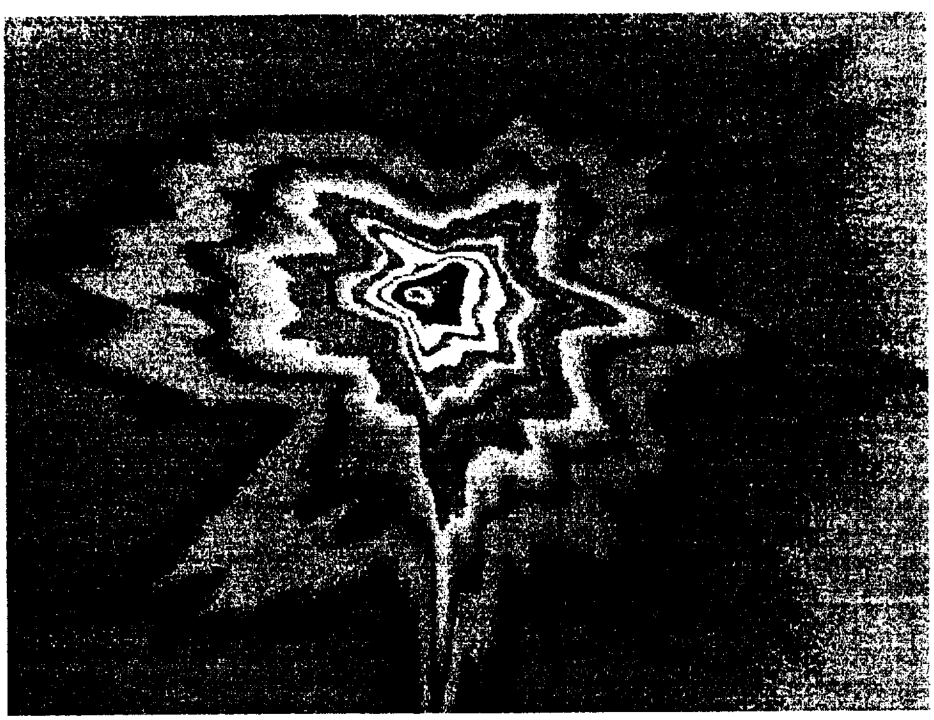

Figure 16. Beam spot after stooping perturbations and at room temperature.

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13. ABSTRACT *(Maximum 200 words)*
Acrylic plastic Fresnel lenses are very light and can have large diameters. Such lenses could be used in lidar telescope receivers if the focal spot is not too large or distorted. This research effort characterizes the focal spot diameter produced by a Fresnel lens with a diameter of 30.5 cm (12 in.). It was found that the focal spot diameter varied from 1.2 mm at 750 nm to 1.6 mm at 910 nm. The focal spot was irregular and not easily described by a Gaussian profile.

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