SF2A 2002
F. Combes and D. Barret (eds)
EDPS Conference Series in Astronomy & Astrophysics

PROTOTYPE CHALCOGENIDE FIBERS FOR 10-MICRON WAVEFRONT MODAL FILTERING

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Abstract

Wavefront cleaning by single-mode fibers has proved to be efficient in optical-infrared interferometry to improve calibration quality. For instance, the FLUOR instrument has demonstrated the capability of fluoride glass single-mode fibers in this respect in the K and L bands. New interferometric instruments developped for the mid-infrared require the same capability for the 8–12 μm range. We have initiated a program to develop single-mode fibers in the prospect of the VLTI mid-infrared instrument MIDI and of the ESA mission Darwin that require excellent wavefront quality. In order to characterize the performances of chalcogenide fibers we are developping, we have set up an experiment to measure the far-field pattern radiated at 10 μm. We report here the first and promising results obtained with this new component.

1 Introduction

Whatever the cause of corrugations on interfering wavefronts, defects on the mirrors or effect of the turbulent atmosphere, they result in a loss in the coherence factor measured by an interferometer. Spatial filtering by a pinhole overcomes this problem by removing the high spatial frequencies from the wavefronts. However, the pinhole has to be designed for a specific wavelength and does not provide a good correction of low spatial frequency defects. An alternative consists in modal

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filtering by a single-mode waveguide: the shape of the wavefronts that have been guided into this device only depends on the characteristics of the guide (choice of materials and geometry); this way, two beams can be recombined with a full interferometric efficiency. This property holds for wavelengths above the cutoff wavelength of the guide, as the only mode to propagate is then the fundamental one.

Unfortunately, no single-mode fiber is available nowadays for the mid-infrared. This is an issue for the VLTI 10-μm instrument MIDI (Leinert *et al.* 2000) and for its ambitious followers on the ground like GENIE (Gondoin *et al.* 2002), or in space like Darwin (Léger *et al.* 1996, Fridlung *et al.* 2000). In this prospect, we have undertaken an activity of research and development with the partnership of Le Verre Fluoré, a leading French company in this sector. In the following, we report the first results obtained with chalcogenide fibers in terms of transmission, wavelength range and modal filtering.

2 Prototype manufacturing

For this applied research, Le Verre Fluoré was funded by the French military administration, la Direction Générale de l'Armement (DGA), and associated to three research laboratories for the full characterization of the produced fibers: the Laboratoire de Physique des Lasers (LPL), the Institut d'Astrophysique Spatiale (IAS), and the Département de Recherches Spatiales (now LESIA). The goal assigned by the one-year contract (dec. 1999–dec. 2000) was to manufacture a single-mode waveguide for the 8–12 μm range with losses less than 3 dB/cm.

Two solutions were selected by Le Verre Fluoré to achieve this goal, as transparent materials in the mid-infrared suitable for fiber manufacturing are either silver halides (e.g. AgCl or AgBr) or chalcogenides (e.g. $\mathrm{As}_x\mathrm{Se}_y\mathrm{Te}_z$). Silver halides have the appealing property of being transparent up to 30 μm with transmission losses that can be as low as 10^{-3} dB/km. However, they are polycristals and as such are turned into fibers by extrusion (the material is pushed through a hole), a process difficult to master. On the other hand, chalcogenides are glasses, so fibers can be manufactured by drawing, but they become opaque beyond 16 μm. In the prospect of the short-term DGA contract, the second solution appeared easier and was prefered. Nevertheless, silver halides are certainly the material that will be needed in the future for applications in the Q band (17–25 μm).

The first fiber prototype was made of $\mathrm{As_2Se_3/GeSeTe_{1.4}}$ with core and cladding diameters of 40 and 210 μm, respectively. It features a numerical aperture of 0.15 and transmission losses of about 0.2 dB/cm ($\approx 30\%$ at 10 μm for our 8-cm prototype). A 8.1 μm cutoff wavelength was measured. A high-resolution transmission spectrum of the material itself was also recorded with the FTS microscope at the LURE in Orsay. This spectrum showed a flat transmission until 12 μm and no significant impurity.

3 Far-field measurements

3.1 LPL testbed

Single-mode fiber theory (Neumann 1988) establishes that the fiber end radiates a free diverging wave beam, the fundamental fiber mode becoming a fundamental Gaussian mode with a good approximation. We have set up an experiment, hosted by the Laboratoire de Physique des Lasers, to check the quality of the modal filtering by measuring the far-field radiation pattern of the fiber (*e.g.* Hotate 1979). The far-field pattern is recorded by moving a single-pixel HgCdTe detector in the portion of space in front of the fiber. The exploration of the 3D far-field pattern (±20° in azimuth, ±5° in height) is done manually, and is completed in about one hour and a half for a resolution of 1°. The experimental procedure was validated by recording the far-field radiation pattern of a 40-μm pinhole, for which the profile had the expected Gaussian shape and width.

3.2 First far-field profiles

The intensity profile radiated by the fiber was not found to be single-mode: only the radius of the whole bunch of modes was compatible with a diffraction by the fiber core, whereas their individual radii corresponded more closely to a diffraction by the cladding. A first explanation could be that the fiber sample is simply not long enough to eliminate the unguided light. However, a previous experiment with a 1-mm long fluoride glass fiber designed for 2 μm and used at 10 μm have shown better results (Perrin *et al.* 2000). The correct explanation was found by taking into account the protective layer surrounding the cladding. This extra layer happens to have a refractive index inferior to that of the cladding itself. This results in a second guiding structure, concentric to the core-cladding pair, that causes persistent cladding modes. As a consequence, the measured transmission figure is probably overestimated as it includes unwanted energy. The problem could be solved if another material were chosen for the protective layer, but at this date, the DGA contract came to an end. Nevertheless, some research could be pursued on a collaborative basis with Le Verre Fluoré.

3.3 Second generation samples

Because of the lack of fundings and despite the lessons learnt from the first campaign of measurements, the fibers produced in the frame of the DGA contract had to be re-used. A second generation of fibers were obtained by removing the extra layer and part of the cladding of the first generation by chemical stripping. Thus, the cladding is studded with diffusive centers favoring the elimination of cladding modes. Besides, the fibers were coated with a new protective enveloppe in lead, a 10 μm absorbent. The two new components are shorter, 4-mm long, with thinner claddings: the core/cladding dimensions are 48 μm/70 μm and 27 μm/45 μm respectively. Figure 1 displays the 1D far-field radiation patterns of the laser beam and of both fibers that were recorded during a second measurement campaign. A best-fit Gaussian curve has been superimposed for comparison. Although there is still a small second lobe in one case (48 μm/70 μm), the profiles appear to be much closer to what we are seeking. However, their width is not completely consistent with the prediction of the standard diffraction theory. We think the cladding is so thin that it can no longer be considered as infinite, as it is usually assumed in the standard fiber theory. The cladding will be thicker when the industrial process is ready. A close examination of the fibers with a binocular microscope has revealed geometrical defects and a small asymmetry of the fiber cores that are lilkely to be responsible for the high frequency defects and the small second lobe. This has been recently improved by Le Verre Fluoré, still using the fibers originally drawn, and we plan to put under test these new components this fall.

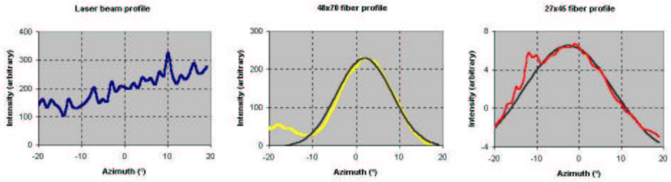

Fig. 1. Far-field radiation patterns (from left to right): laser beam, 48 μm/70 μm and 27 μm/45 μm fibers. Best-fit Gaussian curves in black are superimposed to both fiber profiles.

4 Conclusion

We have presented the characteristics of chalocogenide fibers we are developping to perform modal filtering in the mid-infrared. We have reported promising first results with these components. Because of our present lack of funding, we still work on the fibers that were drawn in the first place. As they could recently be improved nonetheless, and are now ready for testing, we will start a new measurement campaign next fall. If these fibers are successfully tested, they could be integrated in MIDI next year. The following step would be then to develop silver halide fibers for modal filtering up to 20 μm, i.e. through the full wavelength range of Darwin.

References

Fridlung M.*et al.* 2000, *Darwin infrared space interferometer, Concept and feasibility study report*, ESA-SCI(2000)12

Gondoin P. *et al.*, 2002, SPIE, 4838

Hotate K. & Okoshi T., 1979, Applied Optics, 18, No. 19, 3265–3271

Léger A. *et al.*, 1996, Icarus, 123, Issue 2, 249–255

Leinert C. *et al.*, 2000, SPIE, 4006, 43–53

Neumann E.-G., *Single-mode fibers, Fundamentals*, Springer-Verlag, Berlin, 1988.

Perrin G. *et al.*, 2000, SPIE, 4006, 1007–1013