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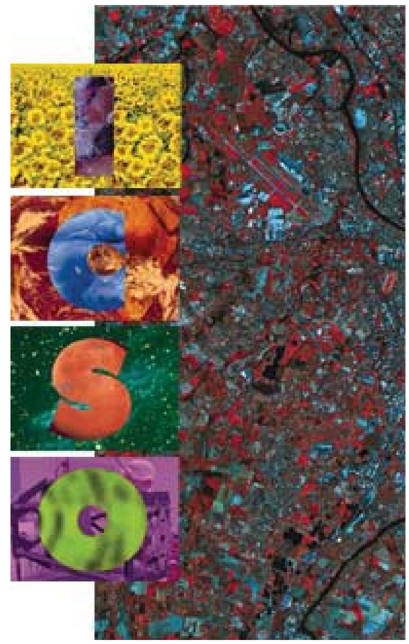

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Single−mode waveguides in thermal infrared wavelengths for spatial interferometry.

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ABSTRACT − Integrated optics, applied to astronomical interferometry, bring several decisive benefits compared to bulk optics : mechanical and thermal stability, small size, facility to realize combiners for many telescopes. At this time, numerous compoments were dezigned, realized and tested for stellar interferometry applications. Laboratory characterization in the VIS/NIR wavelengths confirm the expected capabilities and performances.

At thermal infrared wavelengths, the concept of integrated optics is of great interest for spatial instrumentations and particulary for the Darwin/IRSI mission. The aim of the mission, launched in 2012−2015, is the detection and the spectroscopic study of extrasolar planets. Our long term goal is the development of monomode integrated optic components for thermal infrared wavelengths. In the near futur, we are interested by the conception and the realization of single mode straight waveguide for using in modal filtering.
In this paper, we present the conception of first thermal waveguide and their characterizations. Around different solutions, we focused our attention on the utilization of chalcogenide glasses because of its wide transmission window, from 1 to 20 microns depending of the material composition, and of the potentially low propagation losses.

Keywords : integrated optics, single−mode waveguide, chalcogenide glasse, stellar interferometry, thermal infrared.

• 1 − INTRODUCTION

From it's first use on the sky with the FLUOR instrument, spatial filtering is now commonly used for many interferometric instruments. All the VLTI instruments use it : AMBER [Petr 00] in the near−infrared [1 − 2.5 µm] and MIDI [Lein 00] in the mid−infrared wavelengths [10 − 20 µm]. This is also the case for the ambitious DARWIN [Karl 00] and TPF [Wool 97] projects for which the aim is to search for extra−solar planets. Spatial filtering allow to reduce the effect of the phase disturbence due to the turbulent atmosphere [Coud 96] or to optical quality [Olli 97]. It is achieved

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with optical fibers [Menn 99, Perr 00] or with integrated optics.

Integrated optics in astronomical interferometry [Malb 99, Berg 99] at infrared wavelength is potentially very attractive compared to bulk optics for several reasons: mechanical and thermal stability, small size, facility to realize combiners for many telescopes [Berg 00]. Up to now, at LAOG and LEMO [Kern 00, Hagu 00], we have manufactured, characterized and optimized integrated optic components in the H band (1.65 µm) since the ion exchange technology is well developed for the wavelength ranges 0.6−0.8 µm (microsensors applications) and 1.33−1.55 µm (telecom components).

The integrated optics concept could also be extended for the thermal IR wavelengths but the technology need to be adapted because silica glasses, used for NIR wavelength components, do not transmit over 2.5 microns [Scha 97]. Waveguides for thermal infrared wavelengths are not fully developped, except for some few needs, like the power transmission of CO and CO2 lasers light [Spie 99]. Chalcogenide glasses appear to be an interesting solution because of the large transmission window from 1 µm up to 20 µm. Another advantage is the numerous photoinduced properties (photodarkening, photodissolution of metals, ...) of chalcogenide glasses [Sedd 95]. A Canadian team has yet studied and realized chalcogenide waveguides but for telecom wavelengths. They studied various ways to realized waveguides like the standard photolithographic process used in microfabrication and the used of photodarkening properties of chalcogenide glasses [Vien 99].

At this time, our goal is to realize waveguides with the classical etching process [Laur 00]. The process consist to deposit chalcogenide layers on a silicon wafer or on a silica substrate. Then chemical attack gives us localized waveguides. Section 2 gives a brief description of technological and optical constraints. Section 3 describes properties and glass preparation of chalcogenide bulk. Section 4 describes the process used to deposit thin amorphous film of chalcogenide glasses on substrate. Their chemical and optical properties are described. In the last section, we described the realization and the characterization of planar waveguides.

• 2 − THE CONCEPTION OF THERMAL IR WAVEGUIDES

For thermal IR wavelengths, the technology needs to be developed and tested using new materials while silica glass used for existing components does not transmit above 2 µm. Hereafter, we give a list of constraints which depend on the desired performances of astronomical instruments:

- Transparency spectral range : the material and associated technology should allow a large spectral range in order to justifie the technological developement.
- Low losses : three sorts of losses depend directly of the used material.
    - Propagation losses: we need to use material with low absorption losses.
    - Fresnel losses: they depend on refractive index of the core and grow up with the augmentation of core refractive index (see herafter for details).
    - Coupling losses: coupling losses depend on the profile and the size of waveguides. Ion exchange method produces circular waveguides, which gives a good coupling with incident flux. Etching methods are not well adapted because the rectangular waveguide profile produces elliptical modes and the coupling rate falls down.
- Modal filtering : this is an interesting issue of waveguide optics. Crucial characteristics are:
    - Single−mode spectral range: the spectral range on which the waveguide is single−mode depends on the waveguide dimensions and the refractive index profile.
    - Efficiency of the modal filtering: the single−mode behavior of a waveguide depends on the waveguide profile and on his length. This length need to be chosen in order to have a good filtering [Mege 00].

On the other hand, technology gives us some constraints:

- Waveguide profile : for the etching process, the layers could not be too thick because of process control. To insure single mode preparation, the core layer thickness must be a few times the wavelength leading to thickness of 10−100 μm. This value could be too large for some processes.
- Waveguide length : the dimension of the achievable substrat limits the guide length.
- Layer homogeneity and surface roughness, due to the material and the process will affect the quality of the waveguide.

For the near futur, the required performances of single mode optics are very stringent, especially for the Darwin and TPF missions. Therefore the astronomical specifications and technological constraints need to be mixed in order to find the best compromise.

• 3 − REALIZATION OF CHALCOGENIDE GLASSES

• 3.1 − Main optical and chemical properties

Chalcogenide glasses are made of elements as Se, S or Te, together or with one or some elements as Ge, Si, As or Sb. Theoriticaly, intrisic losses of these glasses are about 0.01−0.1 dB/km. These losses increase to 0.01−0.1 dB/cm for commercial glasses [Koko 96]. These losses are mainly due to absorption by impurity H_2S, H_2Se, oxyde, H_2O molecules,.... Chalcogenide have transparency range in about 1−20 μm and more, depending on the chemical composition. At thermal IR wavelengths, the refractive index of chalcogenide is in the range 2−3.

After a preliminary study of some chalcogenide glasses of different composition, we are now focusing our interest on chalcogenide based on germanium combined with selenium or sulfur. The selected composition is GeX_y with X=S,Se and y=1.5, 2, 3, 5.5. We also studying $GeS_{1.5}Se_{1.5}$ and the classical composition As_2Se_3. These large study permit us to made different combination for waveguide realization. At least two different chalcogenide glasses are required for a waveguide and the choice need to take account of refractive index, transmission window and chemical compatibility. Ge_xS_y and Ge_xSe_y are chalcogenide frequently used for optical application [Sedd 95, Bern 97, Gonz 99]. The use of tellure is more difficult but is interesting because the transmission window is quite increased toward large wavelengths. It is preferable to keep similar composition in order to have analog studies and to have better chemical combination.

• 3.2 − Glass synthesis

The bulk was prepared according to the conventionnal melt−quenched method (see for example [Vien 99]). The elements were weighted and placed in a precleaned and outgassed quartz ampoule, which was evacuated to a pressure of about 10^{-4}–10^{-5} Torr and then sealed. The ampoule was loaded in a furnace and the temperature was gradualy increased to 1000°C with a rate of about 6°C/heure. Then the ampoule was quenched in air.

• 3.3 − Optical characterization

At this time, our interest is the window transparency and the intrinsic losses. The figures 1 and 2 give transmission of Ge_2S_3 and As_2Se_3 bulk. The transmission is measured with a FTIR spectrometer at LMGP (Laboratoire des Matériaux et Génie Physique, Grenoble − France). The

sample was about 1 mm thick and was polished to avoid diffusion of the light. To extract the intrisic losses (propagation losses) of chalcogenide glasses, we need to know Fresnel losses due to reflection at the two interfaces. These losses depend on the refractive index of the bulk. For chalcogenide glasses, as for mostly thermal infrared glasses, the refractive index is high, in the range of 2 to 3 which leads to Fresnel losses of 20 to 45 % (1 to 3.6 dB). At this time, we do not know the refractive index versus the wavelength of our glasses and we could only give an approximation of intrisic losses. For the waveguide, we have also Fresnel losses due to reflection at the two waveguide extremities. These reflection losses could be reduced by appropriate multidielectric coating which is currently done for silica fibers [Rich 97].
The Ge_2S_3 chalcogenide glass has a good transmission between 0.7 and 11 µm. The refractive index is not exactly known but the intrisic losses are estimated to be about 0.5−1 dB/mm.

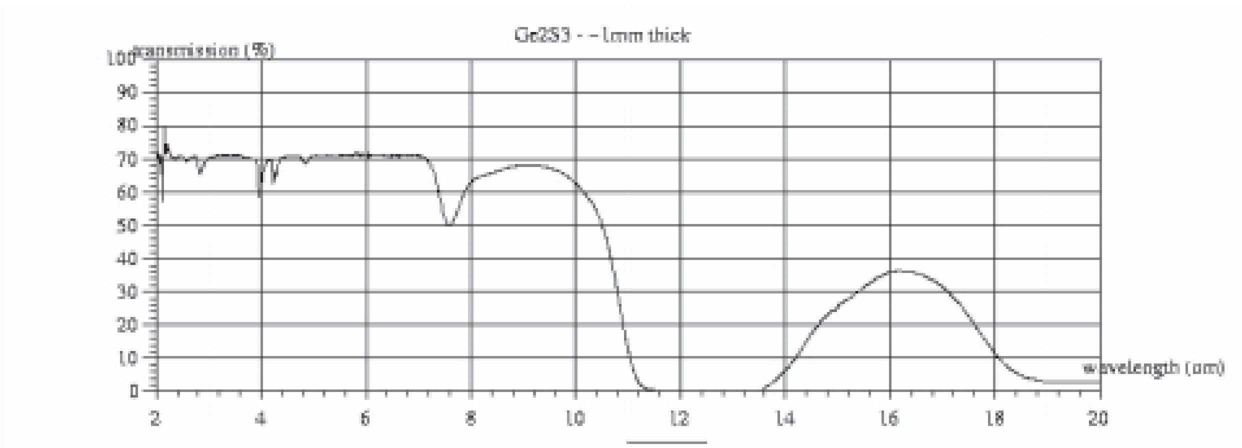

Figure 1 : Spectral transmission of 1 mm thick Ge_2S_3 glass. This curve does not represent the intrisic losses because we need to substract the Fresnel losses. At 10 µm, the intrisic losses are estimated to be of 0.5 to 1 dB/mm.

For As_2Se_3, the refractive index is gived to be 2.771 at 10 µm [Drex 90]. The spectral transmission of our 1 mm thickness sample, is gived on figure 2. With this refractive index, the intrinsic losses at 10 µm are about 0.4 dB/mm. These losses are higher than ones of commercial glasses and need to be improved by remove impurities during glass synthesis.

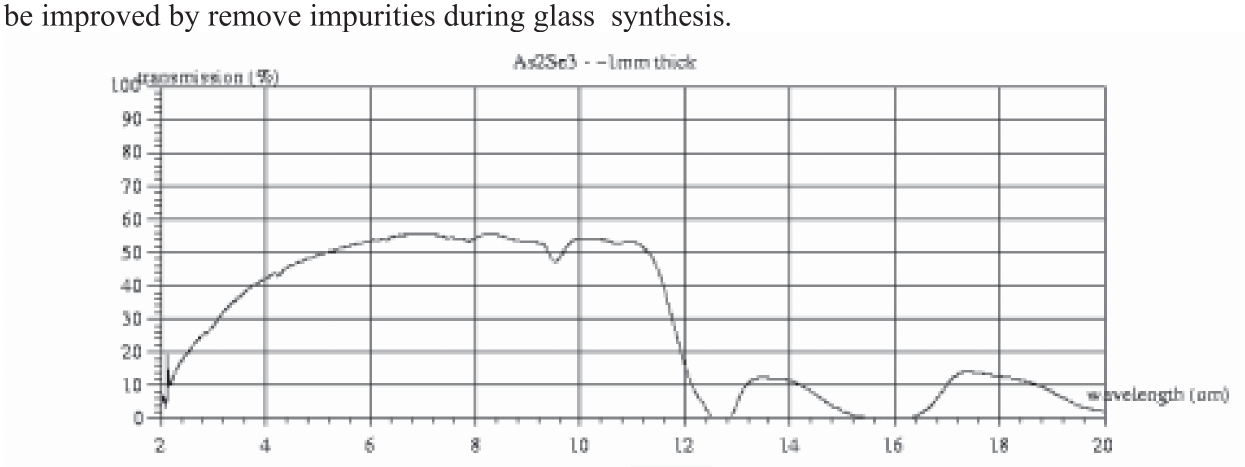

Figure 2 : Spectral transmission of about 1 mm thick As_2Se_3 glass. At 10 um, the refractive index is gived to be 2.771 and the Fresnel losses are about 40 % (2.2 dB) for the reflexion on the 2 faces. The intrisic losses, at 10 µm, are 8% (0.4 dB/mm) for a thickness of 1mm.

• 4 − THIN FILM FABRICATION

• 4.1 − Thermal evaporation

The chalcogenide glass thin film were prepared by conventional thermal evaporation of the bulk glasses at a base pressure of 10^{-4}–10^{-6} mbar, using molybdenum crucibles. The substrates were unheated silicium wafers or microscope slides. At this time, the substrates were not rotated during the evaporation process, so the film thickness is not uniform.

• 4.2 − Thin film characterization

All samples were monitored with SEM (Scanning Electron Microscope) to evaluate the thickness of the chalcogenide layer and to inspect the surface aspect. In some case, the adherence of the layer on the substrate (silicon wafers or silica glasses) is not very good. This could be probably resolved by heating the substrate before the evaporation to eliminate adsorb molecules at the substrate surface. After evaporation, sample could be annealing in order to remove residual stresses and to increase the adherence.

With our deposition process, the thickness of layer is about 1−3 µm. The composition of the layer was studied by Secondary Diffused Electron (EDS). For Ge_2S_3 layer, composition is gived in table 1 and we constate that the composition of the layer is conserved during the thermal evaporation.

Element	Massic percentage of the layer	Atomic percentage of the layer	Theoretical atomic percentage of bulk glasse before synthesis
Germanium	59.73 %	39.58 %	40.00 %
Sulfur	40.27 %	60.42 %	60.00 %

Table: 1 Composition of Ge_2S_3 film.

But the main drawback of thermal evaporation is the non conservation of the stoichiometry of the bulk glasses which is the case for some compositions, for example the GeS_2 layer (see table 2). The stoichiometry is not conserved and the atomic percentage of GeS_2 film became similar to a Ge_2S_3 film. This is also the case for layers which are riched in sulfur. This result, mainly due to thermal evaporation, could be enhanced by using sputtering processes. This issue is one of our next goals.

Element	Massic percentage of the layer	Atomic percentage of the layer	Theoretical atomic percentage of bulk glasse before synthesis
Germanium	63.73 %	41.98 %	33.00 %
Sulfur	38.90 %	58.02 %	67.00 %

Table 2 : Composition of GeS_2 film.

• 5 – WAVEGUIDE MANUFACTURING AND CHARACTERIZATION

• 5.1 – Waveguide manufacturing

We realized two planar waveguides. One is constituted of $GeSe_2$ layer on GeS_2 layer deposed on an oxidized silicon substrate. The second waveguide is a $Ge_{12.5}Sb_{20}Se_{67.5}$ layer on $Ge_{28}Sb_{12}Se_{60}$ on an oxidized silicon wafer. In the two cases, the upper layer is the core and the lower layer is the clad to avoid coupling between core and substrate.
The substrate was cleaved to obtain plane facets. A SEM inspection revealed that the adherence of the two chalcogenide layers is good and probably due to their similar chemical composition. This inspection gived us the layers thickness but we need to recall that the thickness is not uniform. The 2 layers have roughly the same thickness, about 3−4 µm.

• 5.2 – Optical test

The waveguide GeSbSe was tested at 1.55 µm wavelength. This waveguide was about 10x10 mm. Figures 3 shows the output of the waveguide through the clad layer. This flux corresponds to an optical coupling between the clad and the core layer. On the figure 4, we can see the guidance in the core layer. The granulous aspect of ouput is due to inhomogeneity of the layer. We can see that, at 1.55 µm, the waveguide propagates a few modes.

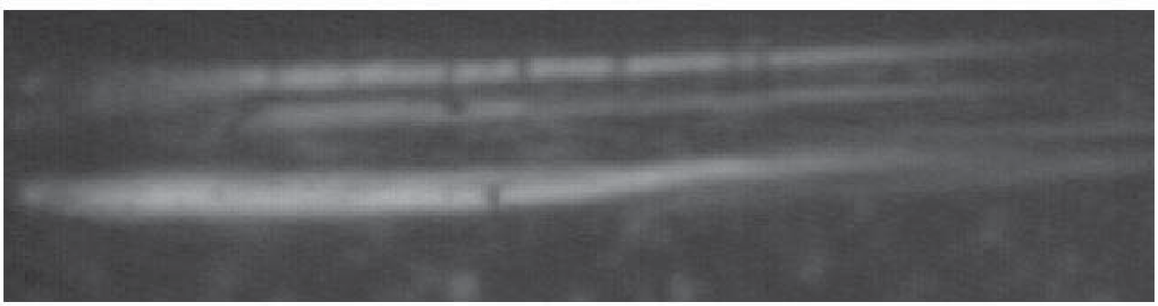

Figure 3 : Injection through the clad layer.

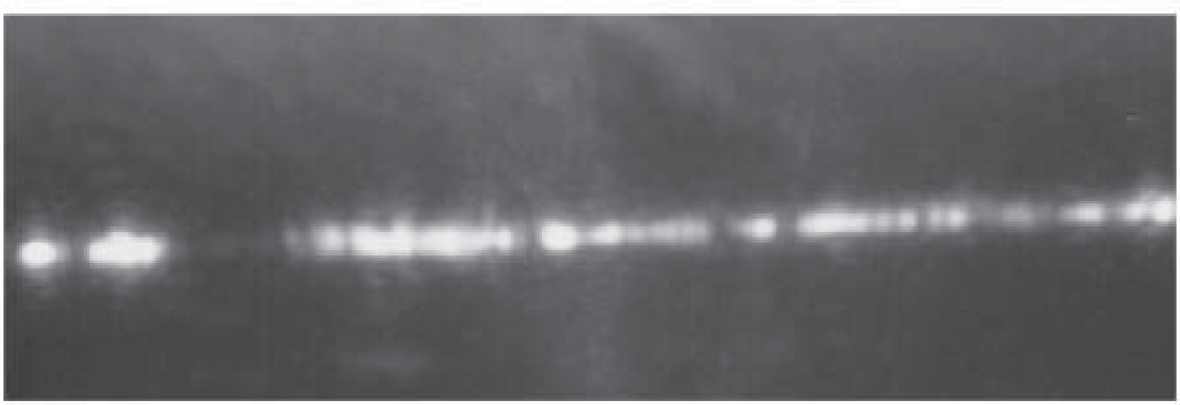

Figure 4 : Injection through the core layer.

• 6 − CONCLUSION

The next step of our studies is to increase the quality of chalcogenide films. With thermal evaporation, the layer homogeneity could be highly improved by heating the substrate just before the and during the evaporation. The substrate need to be rotated during evaporation to obtain a constant thickness over all the surface. An annealing process reduces local stresses and gives an homogeneous layer. Sputtering could give better results but its implementation is more difficult.
Then, we would like to design slab single−mode waveguide. First, we need to know the exact refractive index of our chalcogenide films (this step is actually in progress). We need to evaluate the geometrical conditions to obtain single mode waveguides in chalcogenide glasses for thermal IR wavelength. Next, we could realize single mode confined waveguide by etching layers.

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