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Toward the fabrication of silicon grisms for high resolution spectroscopy in the near infrared

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Abstract. Silicon grisms are suitable optical devices that allow for a spectroscopic mode able to effectively complement the natural imaging mode of IR cameras, providing high spectral resolution (R>5000) in the near infrared.
We present the results of a fabrication process aimed to produce IR grisms with high refractive index. Such devices are intended to implement a high resolution mode in the Near IR Camera-Spectrograph, NICS, the user instrument at the focal plane of the Italian national telescope Galileo. Litho masking and anisotropic etching techniques have been employed to get, firstly, silicon gratings of suitable size for astronomical use, then warm bonding techniques have been used to obtain the final grisms in echelle configuration. The results and the problems encountered in the bonding procedure are presented.

Key words. Infrared Astronomy - Spectroscopy: high resolution - Devices - Grisms

1. Introduction

Grisms are unique optical dispersive elements that allow for a direct-vision spectroscopic mode within imaging instruments without major modifications: the dispersed wavelength, at the needed order, lies along the input optical path. Since the resolving power of these devices is proportional to the refraction index of the prism, only materials with high refraction index, like silicon, can provide resolutions of the order of 5000.

In the frame of the definition of the high resolution spectroscopic mode for the NIR camera-spectrometer NICS for the GALILEO telescope, the Astronomical Observatory of Rome started a technological collaboration with the Istituto di Elettronica dello Stato Solido-CNR (Rome) for the realization of silicon grisms. Also other groups are currently working on the realization of similar devices, but the results are still far from those obtained with standard techniques applied on standard materials (*i.e.* excavating the grooves). This is mainly due to the complex pro-

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cedure phases involved in the realization of such devices: in our case, the lithographic mask, the anisotropic etching and the bonding of the grating with the prism.

A detailed description of both the technological background on which this project relies and the overall fabrication process can be found in Vitali, Lorenzetti & Buonanno 1994, Lorenzetti et al. 1998, Cianci et al. 1999, Vitali et al. 2000 and Cianci et al. 2001. Here, we will review the progress and the problems encountered during the last phase of the fabrication process, that is the bonding of the silicon grating upon the prism surface.

2. The Bonding Procedure

The fabrication of a silicon grism is a complex process, that goes from the writing of the lithographic mask, through the anisotropic etching of the silicon wafer to get a transmission grating and, finally, to the bonding of this latter onto the hypotenuse of a silicon prism. Up to now we have been able to successfully fabricate some silicon gratings (Vitali et al. 2000), which have shown good efficiency when mechanically coupled with the prism. The last step is, therefore, to properly bond the grating onto the hypotenuse face of a silicon prism. This is done by direct silicon bonding, that basically consists of bringing into contact two mirror-polished, flat and clean silicon surfaces, which will adhere to each other because attracted by van der Waals forces; then an annealing in an oxidation tube oven at 800°C is made to strengthen the bond. A sketch of the process is depicted in Figure 1.

A first prototype has been fabricated and a first inspection of the contact surface showed that the bonding was homogeneous. But, after some time, the handling of this prototype led to the detachment of the grating from the prism.

A careful and critical study of all the steps involved in the bonding process has been done, particularly on the cleaning, the polishing and the flatness of the contact surfaces.

2.1. The Cleaning

Before bonding, a careful cleaning procedure of the surfaces must be done, otherwise the presence of dust particles will cause interface bubbles precluding a homogeneous bonding. We realized a teflon holder with a housing where the prism is placed with its hypotenuse face horizontal. The grating's polished back-side is stacked on the prism, with a gap between them ensured by teflon spacers, about 500 μm thick, introduced at the edges. The holder is immersed in a solution of 7:3 H_2SO_4:H_2O_2 for five minutes, and then the gap between the surfaces to be bonded is abundantly flushed by deionized water. This treatment results in hydrophilic surfaces, that means that hydroxyl radicals are present on the silicon surfaces allowing a good initial bond upon contacting. After rinsing with water the rack is put on a spinner where the surfaces are dried at 2000 rpm; then the teflon spacers are removed to put in contact the two surfaces that are bonded. We tested the procedure described above using double-polished silicon wafers cut as squares according to the grating dimensions. The joint wafer pairs were inspected by a transmission infrared video system. In Figure 2 the NIR images show a comparison between a poor (left) and a good (right) cleaned bonding: in this latter attempt, apparently, no dust particles were present, and thus no voids.

2.2. The Polishing

Before the bonding process, we have inspected through an Atomic Force Microscope the surfaces of the grating and prism to be bonded. The prism surfaces were found to be optically worked (about at $\lambda/4$), whereas the grating back surface has been polished via a chemical process that improved the polishing. In Figure 3

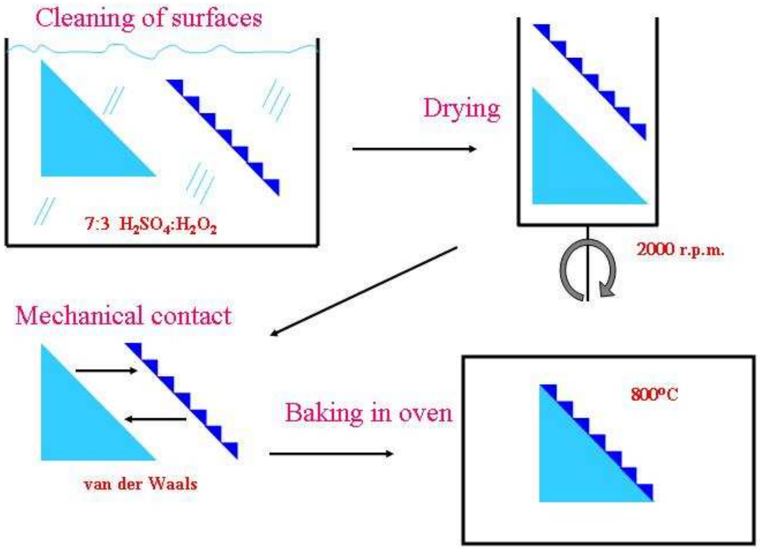

Fig. 1. A sketch of the bonding process.

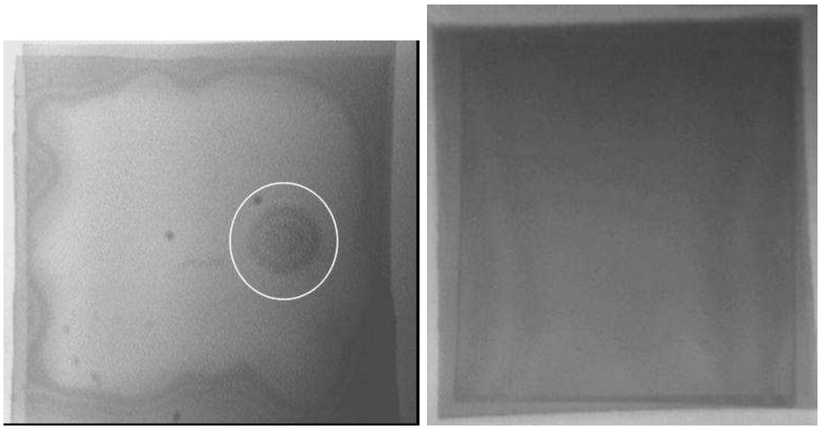

Fig. 2. The effect of air bubbles and dust particles at the interface of the grating and prism surfaces (left) and a good cleaned bonding (right).

we show the surfaces of the prism (left) and of the grating (right). Some tests were performed on a prism with better polished surface but no improvement has been found in the bonding process. Therefore, we decided to adopt the simple optical polishing for the prism.

2.3. The Flatness

The flatness of the contact surfaces is probably the most critical parameter for the optical contact between the two surfaces. We then inspected the flatness of the prism and grating surfaces via interferometry and the results has shown that the prism has

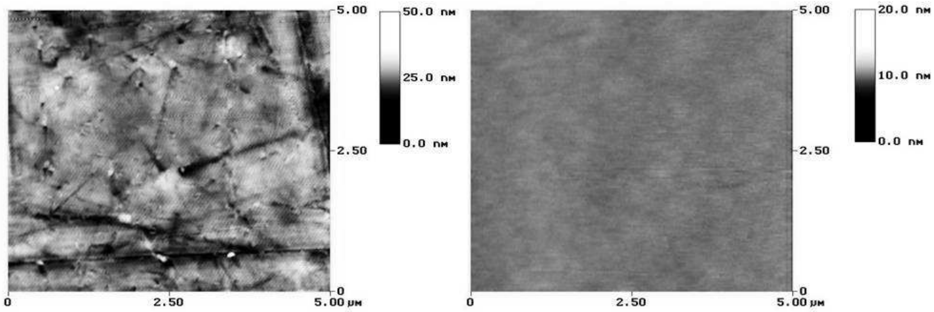

Fig. 3. The polishing of the prism (left) and grating (right) contact surfaces.

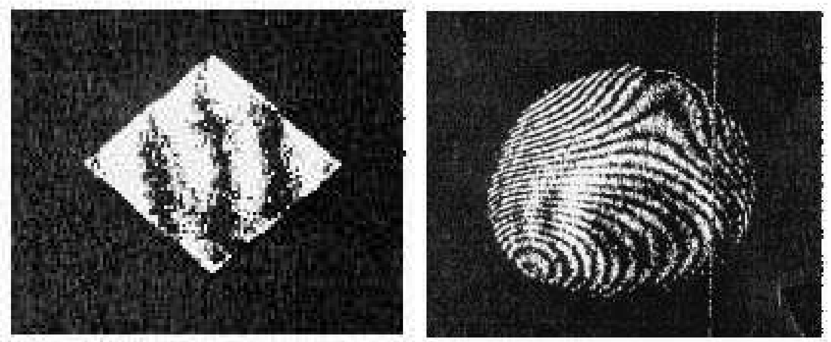

Fig. 4. The interferograms of the prism (left) and grating (right) contact surfaces.

a well flatned surface, whereas the grating shows a strong deviation from a proper flatness (see Figure 4): this is primarly due to the extremely low thickness of the silicon wafer (0.3 mm), from which the grating came from. The poor flatness of the grating lead to a poor optical contact and, as a consequence, a poor melting after the oven warming. To overcome this problem, we are designing an appropriate holder in order to put together the current prism and grating and to hold them in contact, gently but firmly, during the warming phase in the oxidation tube at 800^{o}C.

For the future, we plan to obtain the silicon grating from thicker wafer, at least 1 mm, in order to rely on a better flatness and ensure a better optical contact.

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