Multi-slit mask manufacturing for LIRIS

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ABSTRACT

The manufacturing experience for the Long-slit Intermediate Resolution Infrared Spectrograph (LIRIS) slit masks is presented. The requirements have led to a search for a different approach to multi-slit manufacturing based on Electric Discharge Machining (EDM). The slit profile and material characteristics are discussed in terms of the spectrograph scientific requirements, and test results on prototype masks are presented.

1. Introduction

LIRIS is a near-infrared (0.9-2.4 μm) intermediate resolution spectrograph with added capabilities for multi-object (MOS), imaging, coronography, and polarimetry (Manchado et al. 1998, 2000). This instrument is now being constructed at the Instituto de Astrofísica de Canarias (IAC) and will be installed on the 4.2m William Herschel Telescope (WHT) at the Observatorio del Roque de Los Muchachos (ORM, La Palma).

At spectroscopy mode, LIRIS has 15 slit options: 5 long-slit masks and 10 multi-slit masks. The masks are fully cryogenic (65 K) to work in all near-infrared bands (including K-band), and are mounted on the entrance wheel, inside the cryostat. Although they can be exchanged through a special door at the cryostat well, this process can only be performed at the beginning of each observing period. Consequently the mask design and manufacturing are done several weeks before the observation run.

In the near-infrared spectroscopy, sky subtraction and thermal background establish important constrains to the slit profiles. Therefore, different approaches to the slit mask construction for the standard optical spectrographs have to be taken into account.

2. Slit masks

The slit masks are 74 mm square and 0.25 mm thick covering the LIRIS field of view of 4.2 arcmin square at the WHT focal plane scale of 4.507 arcsec per mm. The long-slit masks are permanently mounted on the entrance wheel with 5 slit widths: 0.111, 0.166, 0.222, 0.554 and 1.109 mm; the length of the slits is 55 mm.

The multi-slit masks are removable and can hold up to 30 slits. The minimum length for the slits is 30 pixels (1.66 mm at the slit mask, considering a detector scale of 0.25 arcsec per pixel). The slits are distributed in an area of 4.2 × 2 arcmin to cover the nominal spectral range.

2.1. Requirements

For long-slits, edge roughness and slit edges parallelism are the critical requirements. These are essential for an efficient sky subtraction when applying the *beam–switch*[2] observing mode. With this mode, stellar object and the sky spectra are integrated from different positions in the slit. To keep the sky subtraction errors to 1% the parallelism and pixel-scale roughness must be within 1% of the minimum slit width (0.5 arcsec, equivalent to 111 μm). The parallelism is defined as the ratio between the variation of the slit width and its length, thus this requirements is set for the full length of the long-slit masks.

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[2] This method consists in moving the object along the slit in different exposures to obtain object + sky simultaneously

For multi-slit masks, the relative slit–to–slit position has to be considered to achieve high multi-slit observing efficiency. The manufacturing error in the dispertion direction should not contribute more than 10% of the expected astrometric error of 0.2 arcsec of the objects included in the multi-slit mask design. At the spatial direction, this requirement can be relaxed by a factor of ten due to the length of the slits.

The slit–to–slit precision is also affected by the *thermal expansion* of the mask due to variations around the working temperature. The stability in the mask temperature is expected to be better than ± 10 K.

The requirements for the mask manufacturing are summarized as follows:

- Slit edge roughness ≤ 1.1 μm r.m.s.
- Slit edges parallelism $\leq 2 \times 10^{-5}$
- Slit–to–slit position error: ≤ 0.02 arcsec (4.4 μm) in the dispersion direction

Both Invar and stailess steel were considered as materials for the masks. Invar has lower *coefficient of thermal expansion* (CTE) than stainless steel; however, the manufacturing of Invar masks is harder because of its strength, and the roughness obtained is not as good as that obtained with stainless steel. With a CTE = 5.028×10^{-6} m/m/K at 65 K (see Rogatto (1993)), stainless steel was selected. For masks made with this material, a 10 K temperature variation produces a change of ± 3.7 μm in the size of the whole mask and, a variation of 0.006 arcsec in the distance of two slits separated 2 arcmin from each other.

3. Manufacturing

Different options for mask manufacturing have been considered. The slit masks requirements were sent to companies that have manufactured slit masks for optical spectrographs. However, none of them said that would be able to fulfill the requirements presented.

Stencil-laser machine manufacturers were also contacted according to the experience described in Szeto et al. (1997); Conti et al. (1999): one test mask sample was obtained from one of the manufacturers. The test mask did not showed the required precision; probably, fine tuning of the laser cutting machine, as described in Conti et al. (2001) would have been necessary. The option of acquiring one stencil-laser was considered; however, the cost of the machine exceeded enormously the budget assigned for the slit masks. Since mask production is limited to 10 masks per observing period, this option was discarded.

An alternative approach was followed by contacting a precision manufacturing company, "Mecanizados Gines S.A."[3] that could manufacture the mask by Electric Discharge Machining (EDM). In this process, the cutting element is the erosion produced by the electric sparks between the electrode, a brass wire, and the mask when a potential of some tens of volts is applied. Both the mask and the electrode are immersed in a dielectric fluid (deionized water).

This method requires the mask material to be electrically conductive. An initial hole has to be drilled on the mask to place the electrode. A high speed Computer Numerical Control (CNC) machine is used for this purpose, which makes a hole with a diameter smaller than the slit width.

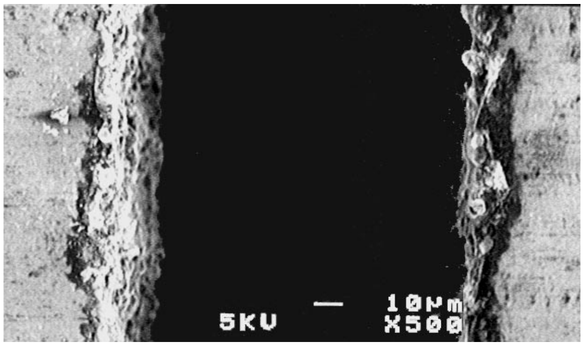

Fig. 1.— Electronic microscope inspection of one 0.7 arcsec slit manufactured by EDM.

4. Prototype testing

Several slit mask samples have been EDM manufactured in stainless steel with different slit widths to verify the accuracy of the cutting process. The slit edges parallelism and the slit–to–slit position error have been measured and the visual inspection has been carried out to estimate the edge roughness.

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[3] www.gines.es

The setup for the measurements is based on a coordinate measuring machine[4] with a microscope and a CCD camera. The profile along the slit in the prototype masks has been measured with a $\pm 1\mu$m error, the instrument precision with the specified setup. Due to the uncertainty in the measurements, this setup has been limited to determine the slit–to–slit positioning error and the slit edges parallelism error.

The edge roughness is a difficult parameter, if not impossible, to be measured directly at the slits. Although an indirect method such as the one described in Conti et al. (2001) is also possible, visual inspection based on electronic microscope imaging was preferred. The roughness is estimated as r.m.s. values (in a pixel-scale) as if it would be measured by a mechanical roughness meter. A sample of a slit of 0.5 arcsec width imaged by the electronic microscope is shown in figure 1.

5. Results

Roughness and slit–to–slit positioning error requirements are satisfied. Parallelism is not satisfied at the full length of the slit; however, for most observing cases (not very extended objects) beam–switch is done using less than half of the slit length. In that case, the parallelism error would produce a maximum of 2% error in sky subtraction.

The *waviness* parameter as defined in Conti et al. (2001) was measured although it was not originally defined at the requirements. Table 5 summarizes the results obtained with the prototype masks.

Table 1: Results from measurements.

Parameter	measured	required
Parallelism	$7 \times 10^{-5} \pm 4 \times 10^{-5}$	2×10^{-5}
Roughness	$1.15 \pm 0.15\mu$m	$\leq 1.1\mu$m
Waviness	$1.4 \pm 0.2\mu$m	—
Slit–to–slit	$3.2\ \mu$m $\pm 2.2\mu$m	$\leq 4.4\ \mu$m

The results on the tests of the prototype masks show that the approach to multi-slit manufacturing based on Electric Discharge Machining (EDM) satisfies the scientific requirements for the instrument spectroscopic mode.

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[4] Mitutoyo FJ805

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