Grism developments for space- and ground-based astronomy

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New manufacturing techniques have led to efficient grisms designed to work in vacuum, ultraviolet, or near-IR wavelengths, and withstand severe space and cryogenic environments.

A grism, a blend of a grating and prism, is a transmission grating ruled on the hypotenuse of a prism. Thus, at a particular wavelength, the diffraction of the grating is compensated by the prism deviation. When a grism is inserted into the imagery channel of an instrument, it produces spectra of astronomical objects without any change in the experimental setup. This unique property renders grisms widely useful in astronomical instruments, performing both imagery and spectroscopy of the same field of view.

Most grisms used in the visible and very near IR wavelengths are manufactured by replicating a ruled master grating on a thin layer of resin deposited on a prism. Nevertheless, limitations of this replication technique appear rapidly when the grism is designed for other wavelengths. Taking as examples three different astronomical missions, we show how we solved the limitations of the classical embossed technique of grism fabrication.

The National Aeronautics and Space Administration (NASA) mission GALEX, launched in 2003, was designed to map the history of star formation. It is a 50cm telescope simultaneously feeding near ultraviolet (NUV) and far ultraviolet (FUV) channels. The dispersive component for the spectroscopic mode is a 75g/mm calcium difluoride (CaF$_2$) grism$^1$ that can be inserted into the convergent beam. This simultaneously produces slitless spectra in the first order for the NUV channel (180–300 nm) and in the second order for the FUV channel (130–190 nm). In the vacuum ultraviolet, the remaining resin layer simply absorbs the UV radiation, which led to a new manufacturing process in collaboration with Jobin-Yvon. Its primary steps are a mechanical ruling of a grating on a gold layer deposited on the 130mm diameter CaF$_2$ prism, followed by transfer of the groove profile into the CaF$_2$ substrate by ion-etching, which completely removed the gold layer. We measured an efficiency of 80% (NUV) and 61% (FUV) in the first and second order, respectively. Figure 1 shows the groove profile, and Figure 2 shows the flight grism with its kinematic mount. The GALEX grism has been working as expected in orbit since April 2003.

EMIR, to be operational in 2013, is a wide-field near-IR multi-object spectrograph to be mounted on the Nasmyth focus of the Canaries Great Telescope (Spain). The extension of EMIR bandpass up to 2.5µm and the required spectral resolution ($R = 3500$) shows the groove profile.
Figure 3. 135mm diameter EMIR grating (800g/mm) transferred into silica.

prevented the use of classical grisms. The resin index could not match the high index of the prism material that is required by the high spectral resolution of EMIR. We designed an EMIR grism that is composed of a transmission grating working in Littrow mode and mounted with air gaps between two zinc selenide prisms. The transmission grating has been produced by Jobin-Yvon using holographic techniques, followed by an ion-etching process to imprint a deep and symmetric profile into the fused silica substrate. This fused silica etched (FSE) gratings technique produced an efficiency of 75% at the blaze with low polarization, and is perfectly suited for the cryogenic (77K) environment of the EMIR grism, because the resin has been completely removed. Figure 3 shows the EMIR FSE grating before integration between the two prisms.

Future space dark energy missions such as EUCLID (phase A closed in May 2011) will require massive spectroscopy of millions of galaxies using a low groove density grism. Since classical ruling techniques have failed to produce a master grating combining a shallow profile with a low groove density (14g/mm), we are investigating photolithography to imprint a sawtooth groove profile in a resin layer. In the context of the research and development program with the National Center of Space Research (France), we developed several photolithographic gratings up to 100mm in diameter. We tested their efficiencies before and after cryogenic cycles (300K–100K) and radiation doses that are representative of the space environment. All of these tests demonstrated that the remaining resin layer is not affected by the severe constraints of space. We measured an efficiency of 75% at 1.5 μm blaze wavelength. The photolithographic process could easily allow introduction of a phase function to correct the remaining aberration, thereby simplifying the optical setup. We produced two prototypes with curved grooves corresponding to a required phase function, and we will test their generated wavefronts in the near future. Figure 4 presents two groove profiles, 14g/mm, obtained by different techniques.

Grisms are widely used in astronomy since they allow easy switching from imaging to spectroscopic mode. With quite different techniques, we have extended their use outside visible and very-near-IR wavelengths in the context of space- or ground-based astronomy. The ion-etching process enables profile transfer in the bulk substrate, which in turn enables high transparency to non-visible light and insensitivity to cryogenic environments. We intend to apply ion-etching to the photolithography process involved in manufacturing very low groove density grisms for cryogenic space missions.

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Figure 4. Photolithographic groove profile obtained with two different techniques. Left: Direct laser writing. Right: Photoplotter. Both profiles were measured with a Wyco Optical Profiler.

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Robert Grange is a senior optical designer with expertise in space spectrographs and dispersing elements. He developed the dispersing elements for several NASA missions (FUSE, GALEX, and FIREBALL) and proposed the new grating for the GRANTECAN-EMIR spectrograph to Jobin-Yvon.

References