JY Division Information

Grating & OEM

Products and Technologies of the Gratings and OEM Division

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Diffraction gratings are used as the key component in optical spectroscopy. As a pioneer and presently world leader in this field, the Gratings and OEM Division of Jobin Yvon (JY) keeps on developing new manufacturing processes for advanced diffraction gratings. This paper shortly presents the different fundamental grating technologies available at JY and later reviews their typical market applications within the scope of the Gratings and OEM Division.

1 Ruled Gratings

The incredible specifications required in the ruling of gratings demand such a high degree of technology, that few places in the world are able to produce them. The ruling engines at Jobin Yvon (JY) are among only 10 to 15 successfully operating ruling engines in the world today.

Ruling of the grating is a slow, arduous process which requires experience, skill and unlimited patience. JY ruling engines normally operate at a speed close to a few hundred strokes per hour. Therefore, in order to rule some gratings, an engine may actually be called upon to operate for as long as a month or more, without failure or even appreciable wear.

The most important parameter in the ruling engine is that the diamond carriage follows an exact path on each stroke. Any lateral displacement would introduce an error in the groove spacing of the finished grating. The carriage rides on perfectly smooth ways under the precise control of a double Michelson interferometer which controls the carriage displacement in order to maintain absolute parallelism and displacement accuracy in such a way that the quadratic error in the position of the grooves is less than 0.001 μm. Given the above described difficulty, and associated high cost, in ruling a grating, most of the gratings actually used in instruments are more affordable “copies”, or replicas of the directly ruled “master” grating.

2 Holographic Gratings

The rapid development of holography started in the early ’60s when lasers became available as coherent sources. The JY team lead by Dr. G. Pieuchard, Dr. J. Flamand as well as Dr. Labeyrie, produced the first holographically recorded diffraction grating in 1967. In addition, the JY team pioneered the use of holography to record aberration corrected gratings which after continued intensive research and development, obtained numerous international patents.

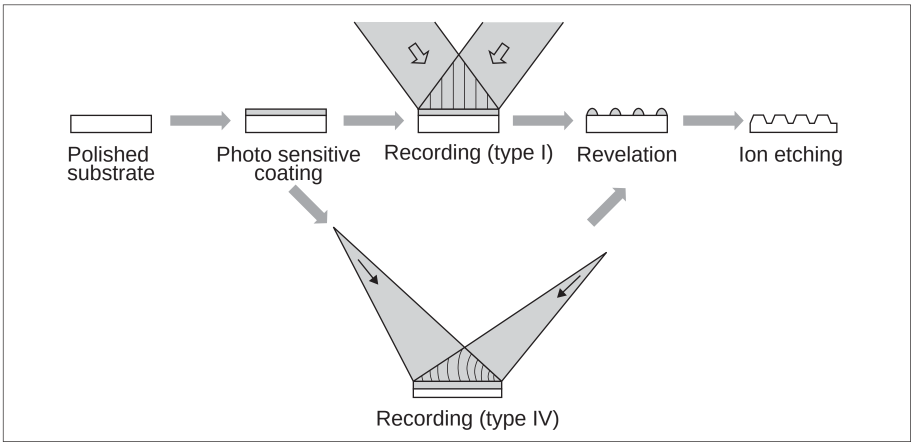

Fig. 1 Holographic Recording

Two beams of monochromatic laser light are used to produce interference fringes in a photosensitive material deposited on an optically flat glass (flat at λ / 10). The interference fringes recorded on the photosensitive material are then developed by an original JY process. The recording and processing are very delicate and elaborate operations.

By designing appropriately and changing the configuration of the interfering laser beams, we can obtain plane and concave type I (or ruled equivalent) gratings using parallel symmetrical beams or type IV gratings, fully aberration corrected, after an optimisation of the recording parameters.

2.1 Type I: Plane and Concave Gratings

For the production of plane and concave type I holographic gratings, the 2 beams are parallel and symmetrical with respect to the normal.

The constant groove density, d, is given by the formula: $d = 2 \sin \alpha / \lambda$, where λ is the recording wavelength and α the half angle between the two interfering beams.

This process yields an equidistant groove distribution. By changing α, we can adjust the groove density as required up to a maximum given by: $\alpha = 90°$ and $d = 2 / \lambda$.

As a result, JY can offer type I holographic gratings with groove densities up to 6000 grooves per mm.

2.2 Type IV: Aberration Corrected Gratings

Type IV aberration corrected gratings are typically recorded using two point sources.

As a consequence, the groove distribution is no longer equidistant and corresponds to confocal hyperboloids or ellipsoids. Optimizing the position, angles and arm lengths of the two sources provides the optical designer with the degrees of freedom necessary to minimize aberrations, typically astigmatism and coma. Auxiliary optics such as gratings (see US patent # 484 2353 “Diffraction apparatus with correcting grating and method of making” from Thevenon et al.) provides the optical engineers with additional flexibility when it comes to recording more specific groove patterns. JY has developed and refined very specific software routines over the last 20 years and can model the most unusual geometries.

These type IV gratings aberration corrected gratings fit especially well the needs of two particular business segments: flat field gratings for spectrographs equipped with array detectors and variable line spacing gratings (VLS gratings) for Vacuum UV applications. Traditionally, when building a spectrograph, concave gratings have been used on the Rowland circle (the circle defined by the grating center and the tangential radius of curvature of the grating). The point source entrance slit is set on this circle and forms a spectrum on this same circle virtually free of defocus and primary coma. While spherical aberrations are generally reasonable, this design suffers from severe astigmatism. As a result, many Rowland circle spectrographs only collect a small amount of the diffracted beam. Fig. 2 illustrates Rowland circle geometry.

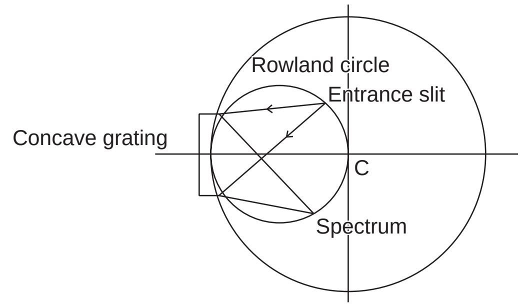

Fig. 2 Rowland Circle Geometry

On the other hand, concave aberrations gratings can be designed to create a linear-like tangential focal curve over specific spectrum ranges. As the flat field grating images a spectrum on a flat and straight line, this configuration is perfect for use with a linear detector array instruments. Additionally, the aberration corrections provide much better light collection efficiency.

This design does not require any other optical parts. A slit, an array detector and the type IV concave aberration corrected grating make up the whole spectrograph and provide the most reliable and simple high performance solution for high volume industrial applications. Fig. 3 illustrates typical concave aberration corrected grating user geometry.

Grating reference : 523 02 120 Option 4

Spherical grating Flat Field

Grooves per mm : 230

Spectral range (Å) : 4000–11000

Length of spectrum (mm) : B_1B_2 = 23.3

L_A (mm) = 137.36

α (deg) = -5.73

L_H (mm) = 131.7

β_H (deg) = 28.8

k = 1

λ (Å)	β (°)	D (°)	Entrance Disp. (Å/mm)	Flat Field Disp. (Å/mm)	L_{Bp} (mm)
4000	11.06	16.79	315.0	293.9	138.28
11000	20.66	26.39		302.7	133.04

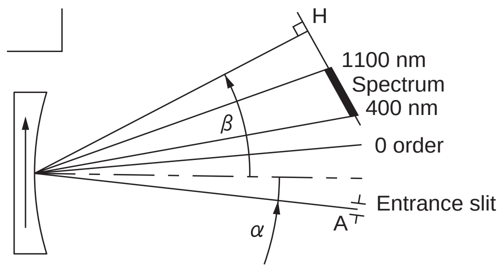

Fig. 3 Typical Concave Aberration Corrected Grating User Geometry

Similarly, for Vacuum UV scientific applications that require maximum photon collection (when the collection of every photon is important), VLS gratings have proved very valuable as these gratings can be optimized to both diffract and focus the beam, thanks to the specific groove patterns, thus saving auxiliary focusing optics that would otherwise waste a large proportion of photons available due to the relatively low efficiency of existing coatings in the Vacuum UV spectral range.

Type IV holographic concave aberration corrected gratings provide the scientific and industrial community with diffractive optics solutions simply not possible to achieve with traditional ruled gratings.

2.3 Signal-to-Noise Ratio of Holographic Gratings

In most applications the important overall factor to the user is the signal-to-noise ratio. The signal level is proportional to the efficiency of the grating. The noise is composed of ghosts and stray light. In general, ghosts designate spurious spectral lines caused by periodic imperfections in the grating.

Rowland ghosts are associated with periodic errors in the lead or pitch of the high precision screw used in ruling engine. Stray light comes from two different origins random non-periodic vibrations, and non-perfect flatness of the reflecting surfaces.

A holographic grating, which is a recording of an interference phenomenon with groove spacing perfectly identical, cannot have ghosts and therefore, has a much lower stray light level than classically ruled gratings. Because of the complete absence of ghosts, holographic gratings generally have a much higher signal-to-noise ratio.

2.4 Etching of Holographic Gratings

In order to obtain a better use of the grating one can think of concentrating spectral energy into any one of the orders (except the zero order). It has been known for a long time that the distribution of energy among orders depended on groove shape. The principle is to rule the grating so that the reflecting elements (grooves) are tilted with respect to the grating surface (saw tooth profile).

Early on, in 1982 JY introduced blazed ion etched holographic gratings. Later on, a new family of profiles emerged when JY realized the benefit of lamellar or laminar profiles: the efficiency of the second order of these gratings is extremely reduced when compared to those of ruled or saw teeth holographic gratings. As a consequence, these gratings are particularly appropriate for applications that include a light source with a very broad spectral range that would otherwise contribute to the noise level of the first order.

The second advantage of these gratings is that they can be etched all the way into the glass making them very robust even to the extremely intense radiations emitted by most intense light sources such as Synchrotron facilities.

3 Replication Technology for OEM (Original Equipment Manufacturer)

The replication process (Fig. 4) is capable of producing thousands or tens of thousands of duplicates of master gratings which equal the quality and performance of the master grating. The replication process substantially reduces the cost of a typical diffraction grating thus making it possible to use replica gratings for industrial applications.

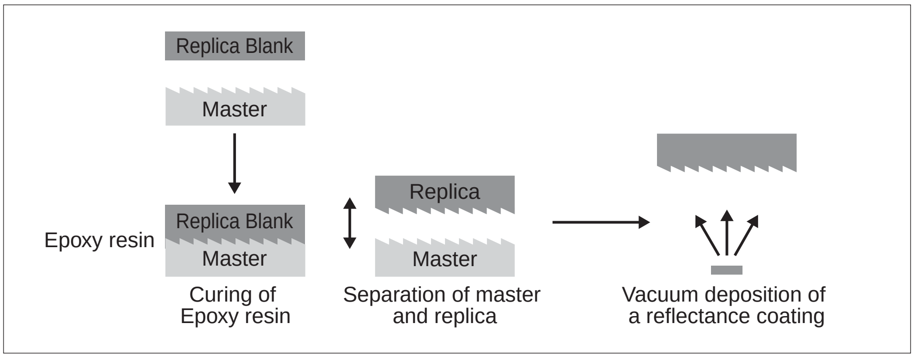

Fig. 4 Replication Process

The replication process starts with the selection of a qualified master. This later is coated under vacuum with a parting layer and a reflecting coating. A substrate is then cemented with a thin layer of resin to the grooved surface of the master. The resin is cured, then the two parts separated. This is a resin casting process. The grooves are moulded in the layer of resin that bonds strongly to the surface of the glass substrate.

4 Advancing the State-of-the-art: LMJ Optics

The Laser Mega Joule (LMJ) is a high energy laser facility under construction in Bordeaux for the French nuclear research agency (Commissariat à l' Energie Atomique, CEA). At completion in 2008, 240 pulsed laser beams will be focused on a 2 mm target, delivering 2 MJ and producing the high density, pressure and temperature conditions where nuclear fusion triggers.

An original feature of the LMJ is the use of large diffractive optics components, where the only comparable system in the world (the American National Ignition Facility at Lawrence Livermore Laboratories in California) uses classical dioptric components.

Thanks to a close cooperation between CEA and JY scientists, the feasibility of this unique components (400 × 400 mm^2 focusing gratings) was confirmed and production started in 2000 for the demonstration prototype (8 to 12 beams).

Fig. 5 presents the SEM profiles of two of the gratings produced at JY, the main breakthroughs that advance the state-of-the-art in holographic gratings being (besides the 400 × 400 mm^2 size which is by itself a world premiere for a commercial company) the number of grooves and the high aspect ratio (1 to 2 μm depth over around 0.5 μm width).

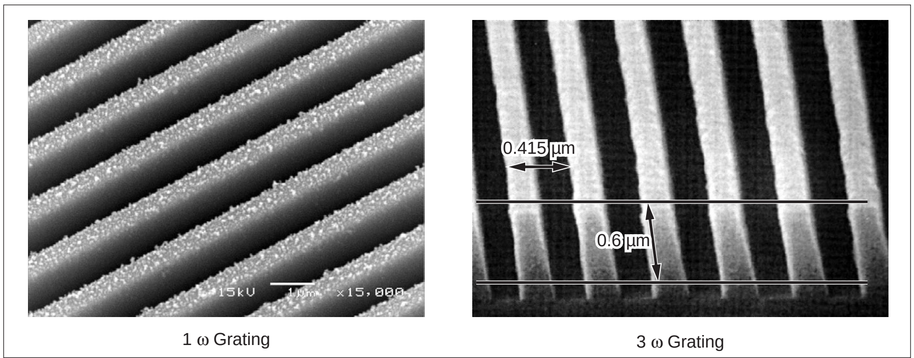

Fig. 5 SEM Image of LMJ Gratings

The gratings operate at extremely high energy levels and their efficiency (in this application the gratings are used in transmission mode and the efficiency measures the ratio between the transmitted and incident energies) must be as close to 1 as possible, to maximize the total energy transfer of the system and avoid damaging the gratings with dissipated losses.

Fig. 6 maps the efficiency achieved across the surface of a grating and along an X axis cut, at many points the theoretical maximal efficiency of 95 % is reached and the average is above 90 %, better than the challenging specification from CEA.

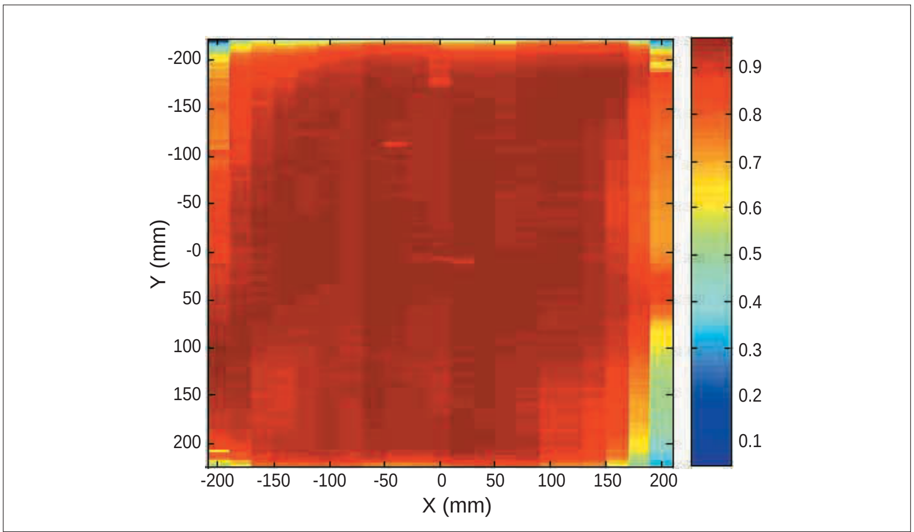

Fig. 6　Efficiency Distribution of LMJ Gratings

This cooperation with CEA scientists has allowed JY to improve its state-of-the-art as a leader in holographic gratings and this will benefit to all gratings produced at JY.

Fig. 7 shows the large custum grating for the French Megajoule Program.

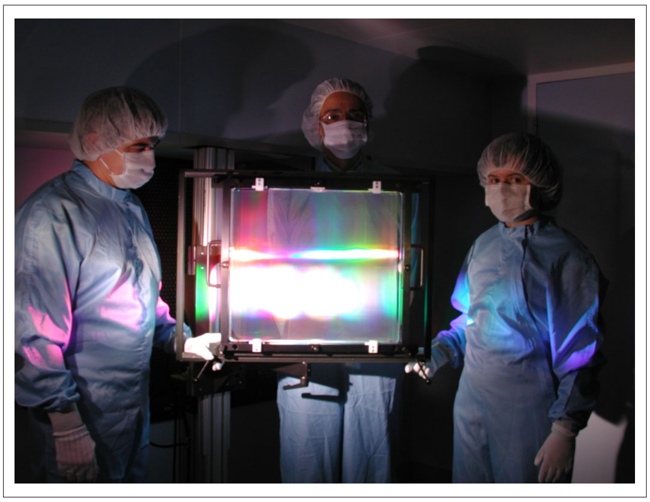

Fig. 7　Large Custum Grating for the French Megajoule Program

5 Servicing the Optical Spectroscopy Market

Diffraction gratings constitute the key component of most optical spectroscopy applications. Building on its knowledge of gratings, the Gratings and OEM Division further developed its commercial reach by packaging gratings with other technologies to satisfy end-user markets.

The Gratings and OEM Division pursues with the scientific community innovative diffraction grating based solutions through pioneering and development of new technologies. These innovations are then made available to industrial users through our OEM group which brings additional value to our OEM customers by proposing integrated optical systems as well as components.

The division is organized around three product lines.

5.1 Custom Gratings

This product line addresses the needs of the scientific community for very specific, high performance diffraction gratings. The Custom Gratings product line excels in designing and manufacturing specialised diffraction gratings for applications including: space flights, astronomy, high energy lasers, pulse compression and synchrotron sources.

For over 40 years, JY has been playing a leading role whether for the design, development and manufacture of master and/or replica diffraction gratings.

Some commercial first include:

- Holographic diffraction gratings
- Aberration corrected gratings
- Concave gratings development
- Ion etched gratings for synchrotron applications
- Gold coated pulse compression gratings
- Multi-layer dielectric pulse compression gratings

Ground breaking work such as the recent development of large high efficiency, high energy transmission gratings for the French MegaJoule program is only one well publicised example of JY's long standing tradition of innovation in the field of diffraction grating technology. As a matter of fact, JY is often selected by NASA or ESA for their most demanding missions. For example JY supplied the first 400 × 400 mm^2, 6000 grooves per mm aberration corrected grating for the Lyman Fuse mission. Similarly, the Hubble Telescope is equipped with an imaging spectrograph, STIS whose gratings are JY'. Recently, in December 2000, JY received a rare NASA award in recognition of the "holographic gratings for the COS (Cosmic Origin Spectrograph) instrument that will enable a new generation of scientific exploration for the Hubble Space Telescope".

5.2 Vacuum UV Monochromators and Beamline Product Line

This Product line stems from our synchrotron grating experience backed by our spectroscopic instrument manufacturing capability. The main target of this Product Line has traditionally been Vacuum UV spectroscopy equipment geared for synchrotron facilities - from individual components to complete monochromator beamlines.

Through this activity JY has been able to provide Vacuum UV instrumentation to the wider scientific community as the whole by proposing smaller vacuum compatible table top monochromators and spectrographs. Applications for such instruments range from plasma analysis, X-ray lasers, surface analysis, UV ellipsometry to semiconductor characterisation.

5.3 OEM Product Line

The OEM (Original Equipment Manufacturer) product line brings opto-mechanical spectroscopic expertise to help industrial customers control their costs and create innovative solutions based on the latest progress in grating technology, as well as our own spectroscopic instrument manufacturing experience.

The OEM product line offers replica gratings, instruments (monochromators and spectrographs), CCD Detectors to industrial customers, as well as fully integrated systems (from light source to detectors). Contract Manufacturing projects including optical sub-assemblies are also an additional service to our OEM customers.

This product line has established an outstanding reputation for on time deliveries and reliability. Our experienced engineering team welcomes any cooperative effort to review potential solutions to specific market needs. Typical applications range from Telecommunications, colorimetry, analytical chemistry, semiconductor to biotechnologies.

Fig. 8 shows the OEM products, and the different industrial flat field spectrographs is shown in Fig. 9.

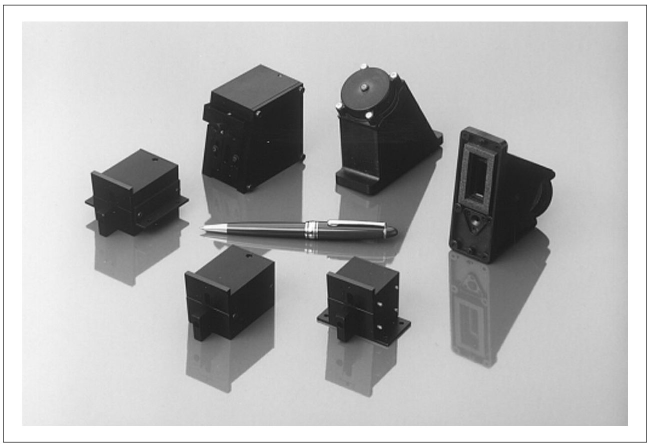

Fig. 8 OEM Products

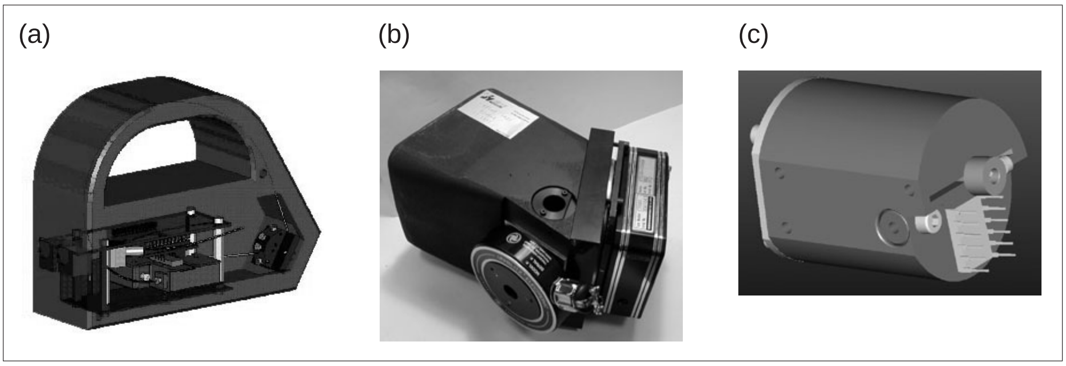

Fig. 9 Different Industrial Flat Field Spectrographs
(a) Double CP20 for Colorimetry
(b) CP140 Equipped with Detector and Shutter
(c) CP30 Design for Biotechnologies

6 Conclusion

The Grating and OEM Division of JY continues to develop the diffraction gratings technology and promising initial results can be noted using optimized multi-dielectric layers to further improve the state-of-the-art. In this way, this Division strives to remain at the best scientific level, playing its role as a center of excellence in diffractive optics inside JY.

Developments oriented towards commercial applications remain driven by an attentive listening to the different market requests, focusing on targets where leading world positions as well as minimal market size can be attained.

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