Jobin Yvon Diffraction Gratings: A Core Technology and its Applications

Dr. Michel Mariton

Abstract

A diffraction grating is an optical component that disperses the different wavelengths of an incident light. It is used as the key component in optical spectroscopy, telecommunication multiplexing or laser systems, for example. As a pioneer and presently world leader in this field, Jobin Yvon (JY) has developed the manufacturing of advanced diffraction gratings as its core technology and pursues the applications of this technology either on its own (Raman spectroscopy, spectrofluorometry ···) or with partners.

1 Introduction

Jobin Yvon (JY) was created in 1819 in Paris by J-B. Soleil and collaborated in its early days with famous scientists, including the manufacture of lenses for Augustin Fresnel's experiments. From this prestigious foundation, the company has always strived to combine scientific excellence with commercial reach, as illustrated by the present ratio of 85 % of the turnover achieved outside its French homeland.

Using diffraction gratings as an example, this paper will present the development of JY fundamental technologies and their interaction with market understanding to deliver timely new products to well identified users.

JY joined the HORIBA Group in 1997, thus complementing its scientific and marketing strengths with the power of a larger company, in terms of financial backing, product engineering know-how and quality culture. The ultra thin film analyzer for 300 mm semiconductor wafers (UT-300) will be used to illustrate the capability of this alliance.

Finally this paper will conclude by outlining some perspectives for our future dreams.

2 Diffraction Gratings

2.1 Ruled Gratings

Since American astronomer, David Rittenhouse, constructed the first known diffraction grating in 1786, several attempts were made to produce quality gratings for scientific use. It wasn't until the late 19th century when Professor Henry Rowland of Johns Hopkins University began producing gratings on sophisticated ruling engines, that the ruled diffraction grating made an impact on the field of spectroscopy.

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 JY are among only 20 successfully operating ruling engines in the world today.

In its theoretical form, the diffraction grating comprises a large number of fine slits, parallel and equidistant and located in the same plane. In practice, these slits are replaced by parallel ruled grooves.

One of the main characteristics of a grating is its spacing, i.e. the separation of corresponding points on two adjacent grooves. The spacing is more currently referred to by its reciprocal, or grating constant: the number of grooves per millimeter. The needs of spectroscopy have given rise to the ruling of finer and finer gratings, comprising a higher and higher number of grooves per millimeter and the difficulties of achieving this ruling have increased in consequence.

A further difficulty arises from the fact that the qualities of a grating are closely connected to the degree of precision with which the straightness, parallelism and equidistance of the grooves are controlled.

Finally, the profile of the grooves, which is determined by the intended purpose of the grating, must be maintained constant from the first to the last groove. Therefore any wear of the ruling tool in the course of operation must be controlled.

In the specific case of the ruling of concave gratings, the profile must remain rigorously uniform along the groove because the ruling diamond is not displaced parallel to itself, but rather its motion is about the center of curvature of the grating. This has the prime effect of eliminating appearance defects in the form of eccentric circular zones, and moreover, enables the ruling of concave gratings of unequalled apertures. The advancing mechanism is controlled by a double interferometer and results in gratings where the ghosts (or unwanted spectral lines), are negligible, even in the highest orders.

Ruling of the grating is a slow, arduous process, which requires experience, skill and unlimited patience. JY ruling engines normally operate at a speed of 600 strokes per hour. Therefore, in order to rule some standard gratings, an engine may actually be called upon to operate for as long as 90 days 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.

2.2 Holographic Gratings

D. Gabor first discovered the principles of holography in 1948 ; his 1971 Nobel Prize was the acknowledgment of this exceptional work.

The rapid development of holography started in the early '60s when lasers became available as coherent sources. Based on an original work of Dr. A. LaBeyrie, an astronomy professor now at College de France, the JY team lead by Dr. G. Pieuchard and Dr J. Flamand, produced the first practical 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.

JY is now one of the very few companies in the world to offer high quality holographic diffraction gratings along with a full line of ruled gratings.

Fig.1 illustrates the principles of holographic gratings production.

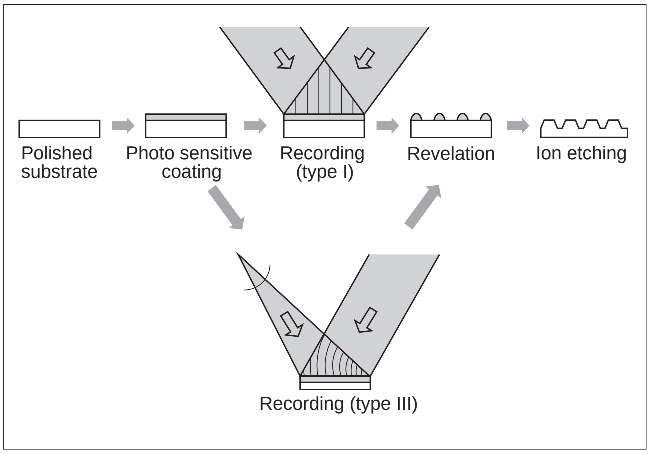


Fig.1 Holographic Recording

Two beams of monochromatic laser light are used to produce interference fringes in a photosensitive material deposited on an optically flat glass (flat at l/10).

An original JY process then develops the interference fringes recorded on the photosensitive material. The recording and processing are very delicate and elaborate operations.

By changing the configuration of the laser beams, one can obtain plane and concave type I (or ruled equivalent) gratings (parallel symmetrical beams) or concave type II (or aberration corrected) and III (or stigmatic) gratings (non parallel beams).

JY can offer holographic gratings with as many as 6,000 grooves per millimeter and every year manufactures several tens of thousand of replicas from ruled and holographic masters.

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

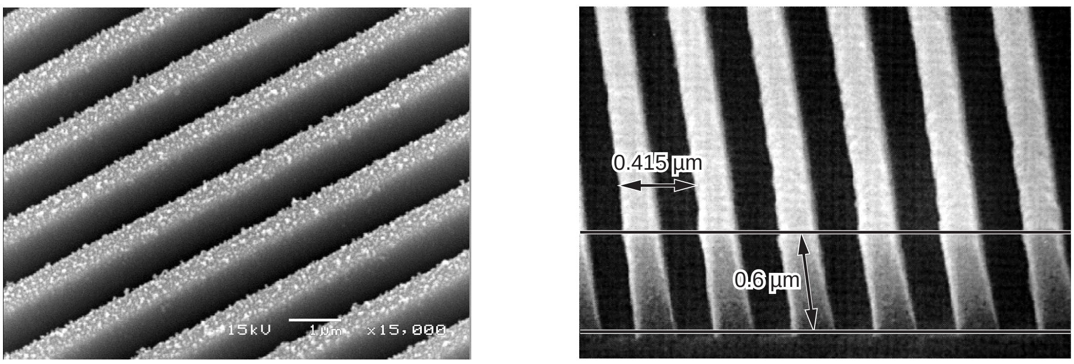
The Laser Mega Joule (LMJ) is a high energy laser facility under construction in Bordeaux for the French nuclear research agency (Commissariat à l'Energie Atomique, CEA). At completion in 2008, 240 pulsed laser beams will be focused on a 2 mm target, delivering 2 MJ and producing the high density, pressure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

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

After a close cooperation between CEA and JY scientists, the feasibility of these unique components (400 × 400 mm^2 focusing gratings) was confirmed and production started in 1999 for the demonstration prototype (8 to 12 beams).

Fig.2 presents the SEM profiles[*1] 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).

The gratings will 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.3 maps the efficiency achieved across the surface of a grating and along an X-axis cut. At many points the theoretical maximum efficiency of 95 % is reached and the average is above 90 %, better than the challenging specification from CEA.



1 omega grating

3 omega grating

Fig.2 SEM Profiles of the Gratings

Fig.4 is a picture of the large transmission grating.

This cooperation with CEA scientists has allowed JY to improve its state-of-the-art as a leader in holographic gratings. Further, in order to satisfy the CEA needs to 2008 and beyond, all gratings produced at JY will benefit, and consequently all JY made instruments.

*1 : The beam frequency (hence pulsation) is tripled along the light path, 1 omega and 3 omega gratings are thus just two kind of gratings used at different positions in the system.

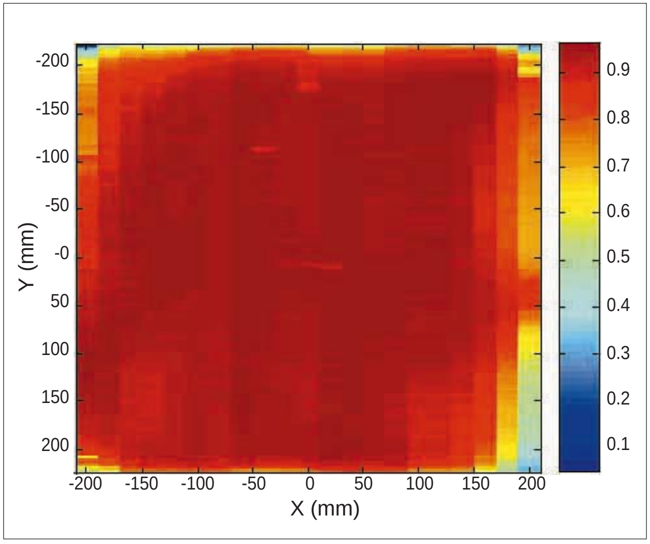


Fig.3 Efficiency of a Focalizing Grating

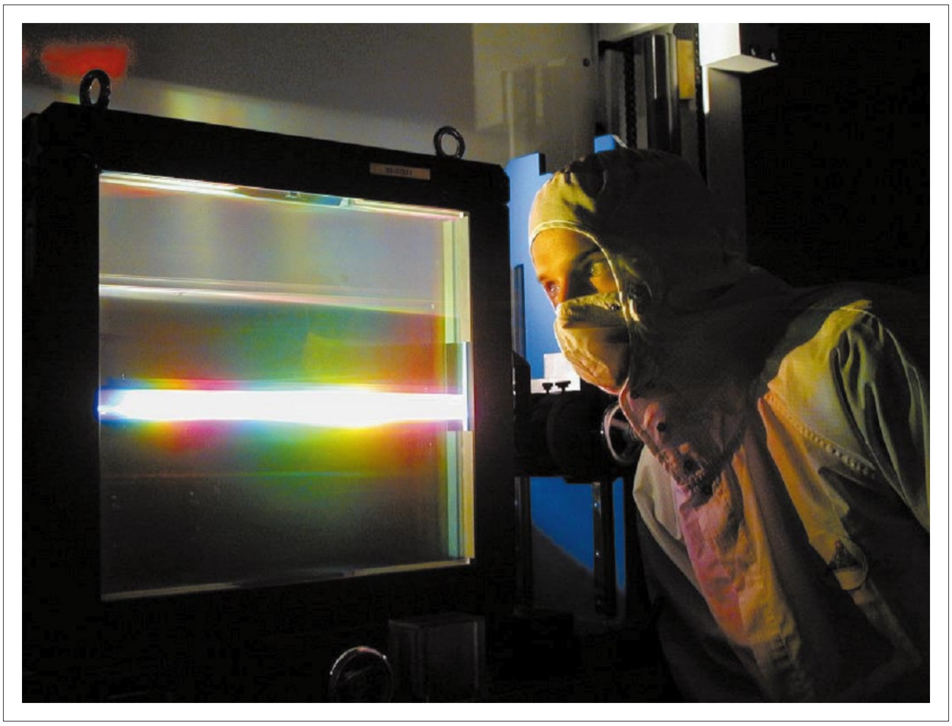


Fig.4 Large Transmission Grating

3 Serving the Optical Spectroscopy Markets

Diffraction gratings constitute the key component of an optical spectroscopy application and, building on its knowledge of gratings, JY further developed its commercial reach by packaging gratings with other technologies to satisfy end-user markets (Fig.5).

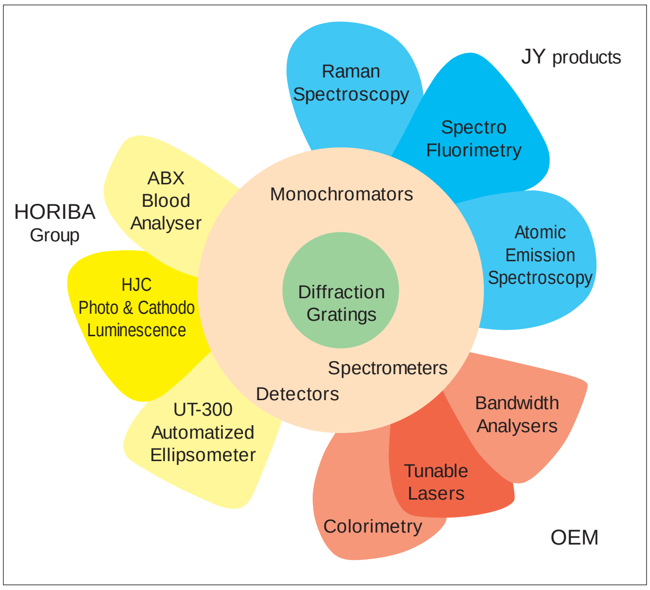


Fig.5 From Gratings to Spectroscopy

Of particular significance is the use of JY core optical engineering capability in synergy with the power of the HORIBA Group to develop innovative products such as ABX Pentra 400 or HORIBA UT-300 (Fig.6).

Fig.6 UT-300: a Fully Automatic Spectroscopic Ellipsometer

JY pioneered the commercial use of spectroscopic ellipsometry througha collaboration with the French Ecole Polytechnique. Prof. B. Drevillon and his team there had developed a phase modulation solution that significantly improves the signal-to-noise ratio and the speed of measurements. JY industrialized this research in the late 80's as the UVISEL table top ellipsometer, still today a leader in its field which received the CNRS award in 1996. Besides core optics, electronics and mechanics technologies, ellipsometry also requires powerful modelling and optimization algorithms and this led JY to enlarge its technical base by adding applied mathematics and software engineers to its team.

After joining HORIBA in 1997, it became apparent that spectroscopic ellipsometry could play a role in the semiconductor strategy of the group: ellipsometry is particularly well suited to characterize complex layers of transparent films and measure their thickness. As the semiconductor industry evolves towards smaller critical dimensions, there are situations, like ultra thin gate oxides, where ellipsometry is one of the very few techniques that can do the metrology job.

It is then needed to package a UVISEL-like sensor with a robotized wafer handler, sorting up to 200 wafers per hour, and to develop a software interface with the fab automation system. This was only possible by adding the strength of HORIBA's Kyoto R&D center to JY's, thus illustrating the value of an alliance where advanced optical engineering and the power of an instrumentation leader come together.

4 Conclusion

JY will continue to develop its core 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, JY will strive to remain at the highest scientific level, playing its role as a center of excellence in optics for the HORIBA Group.

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

Cutting edge technology and market focus, in alliance with the power of the HORIBA Group, will allow us to play our role in the long chain from Atelier J-B. Soleil in 1819 towards remaining a respected brand and global leader in optical spectroscopy ··· in 2019!

Acknowledgements: The author acknowledges the support of Dr. J. Flamand, F. Bonnemason, Y. Josserand and their LMJ project team who produced the gratings presented in this paper under the direction of O. Nicolle, JY Gratings Manager. The UVISEL and UT-300 developments are based in Chilly Mazarin, under the direction of Dr. R. Benferhat, JY Thin Film Manager.

Dr. Michel Mariton

Jobin Yvon S.A.S.
Director General