Vacuum Ultra Violet Monochromator

Erick Jourdain

Abstract

Taking the advantage of Jobin Yvon(JY) leading position in the design and realisation of diffraction grating JY has developed over the last past 30 years some of the most innovative Vacuum Ultra Violet (VUV) monochromators for synchrotron centre. These monochromators, which combine the ultimate advanced diffraction grating technologies and some ultra precise under vacuum mechanics, have been installed in several synchrotron centres and have demonstrated superior performances. Today the development of new compact VUV sources and applications require compact VUV monochromators. Based on diffraction grating capabilities and our large experience acquired in the difficult and demanding market of under vacuum synchrotron monochromators JY is currently developing new compact monochromators for application such as Extreme UV lithography or X-ray Photoemission Spectroscopy.

1 Introduction

In the middle of the seventies thank to the development of the aberration corrected holographic toroidal gratings at Jobin Yvon (JY) we introduced on the market a new VUV monochromator concept that drastically enhanced the spectroscopic performances in this field [1]. During the eighties the Toroidal Grating Monochromator (TGM) and its associated toroidal gratings had a large and world wide success. At that time most of the synchrotron VUV beamline got equipped with this monochromator type and even today some recent beamline are still been developed around TGM like the one manufactured and installed in 2001 - 2002 at Daresbury (UK). This monochromator is a perfect example of our under vacuum mechanical system capabilities as its scanning mechanism (goniometer) exhibits a weight of around 100 kg in order to handle up to three 300 mm × 80 mm gratings interchangeable under vacuum while the angular scanning resolution of the goniometer is equal to 0.4″ (arcsec) (Fig. 1).

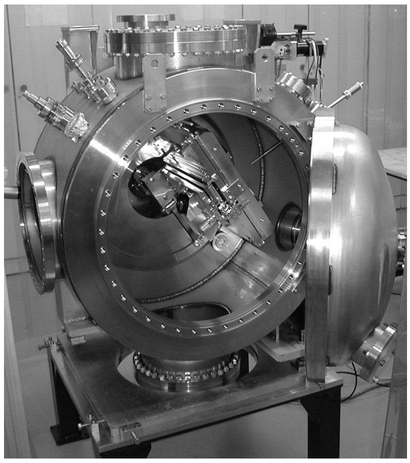

Fig. 1 Inner View of Toroidal Grating Monochromator Chamber Installed at Daresbury (UK)

Following the development of the TGM and associated grating JY started some collaboration with synchrotron scientists to continue the development and manufacturing process of diffraction grating and associated monochromators. Especially the last generation of synchrotron source has required during the last decade a large R&D effort to adapt the instrumentation to new huge power emitted by the source.

The synchrotron sources have been over last three decades used for experiment that required Vacuum Ultra Violet light between 1 and few hundreds nm, thanks to its continuous and bright emitted spectrum. Nevertheless synchrotron required huge and expensive instrumentation that limits its availability. Today the development of new compact sources, such as capillary discharge or laser induced plasma, already enables tabletop VUV experiments with significantly less equipments than in synchrotron cases. The JY VUV group already offers a complete range of compact monochromators and spectrographs especially adapted for this growing market of compact VUV application. Examples of such compact instruments are presented in last part of this paper.

2 Synchrotron VUV Instrument

We at JY focus our effort on new optical components, monochromator designs and components in collaboration with synchrotron centres to increase the resolution, the flux and minimises the harmonic rejection of the monochromator. The third generation synchrotron sources brilliance has developed a need for especially dedicated instrumentation (cooling optics, high resolution monochromators, stable mechanics, etc.) adapted to the source parameters.

In middle of the 1990 s, JY started a R&D program in collaboration with LURE (Orsay, France) optical group to develop new beamlines and components well adapted to third generation synchrotron sources. One of the first steps of the program was the development of three dedicated software to optimise and simulate grating and beamline performances and therefore be able to propose complete project study starting from definition phase. A short description of the three developed software are presented hereafter.

(1) Grating Efficiency Calculation

As the main part of a monochromator the grating needs to be optimised in terms of efficiency and high order rejection. Calculation of grating efficiency and harmonics contamination is done thanks to a JY software. This software based on the electromagnetic theory includes some optimisation algorithms, which give the possibility to define grating parameters (groove depth, c/d) for any specific VUV configuration where no commercial software is available.

(2) VLS Grating Holographic Parameters Calculation

In some VUV monochromator optical designs aberrations are corrected using VLS (Variable Line Spacing) gratings, which means that the groove density is given by a polynomial law. JY already proposed a similar solution in 1975 in the Toroidal Grating Monochromator design where aberrations is corrected with a non uniform groove density grating obtained by interference of two spherical wavefronts. Like in the TGM case the VLS grating density can be obtained by interference of two wavefronts, which give all the advantages of holographic recording grating (no ghost, less stray light). Definition and optimisation of holographic recording parameters that permit to produce the VLS law on the grating is performed with software developed in JY [2], which calculates the interference produced by plane, spherical or aspherical recording laser wavefronts.

(3) Beamline Ray Tracing and Optimisation

JY can ray trace any VUV system starting from the source (undulator, wiggler, bending magnet, etc.) up to the experimental chamber with software especially developed for grazing incidence optics. With this tool any instrument or beamline performance taking into account slope errors and roughness of the optical surfaces can be checked and optimised by a minimisation of a merit function.

Taking benefit of these simulation softwares JY has developed a new beamline for the second-generation storage ring, the SACO (LURE in France) *. This storage ring is in operation since 1986 and presents some characteristics such as high emittance (source size), low brilliance and floor vibration not optimise for high resolution spectroscopy beamline. The challenge of this beamline was to realise a monochromator with the highest possible performance in the Extreme Ultra Violet (EUV) range. The different constraints of the project were determined by the end users and the SACO hall experiment environment: The monochromator have to cover an extended wavelength range (30 - 250 nm) with a spectral resolution ($\lambda/\Delta\lambda$) better than 150,000 over the whole spectral range. This design goal was of the level of the highest spectral resolution never achieved on a synchrotron beamline but with a fixed monochromator (no wavelength scanning).

* LURE is the French synchrotron radiation laboratory located at Orsay in Essonne. It is under joint management by the CNRS / CEA / MENRT (UMR 130). It has two storage rings (DCI and SACO) which produce photons of energies ranging from IR to 50 keV, a free electron laser working in the IR – from one micron to 50 microns – (CLIO), and a free electron laser on SACO.

Fields of application using the SACO
- Atomic and molecular physics
- Solid state physics
- Surface physics
- Biology
- Chemistry
- Optics and detectors

http://www.lure.u-psud.fr/

Above 30 nm normal incidence optical configuration can still be used as some material presents reflectivity close to 30 %, which is no more the case below 30 nm. Nevertheless this reflectivity of 30 % does not allow optical configuration with numerous optics in order to maintain relatively high monochromator throughput. Therefore a solution with a single optics monochromator based on a slightly modified Rowland circle principle (Eagle off plane) was chosen. In this design a spherical grating is the only optical piece that performs the dispersion of the light and the focalisation. The main difficulty in Rowland circle design is the non constant position of the spherical grating focal point, which moves during the wavelength scanning. In order to maintain the exit slit position fixed it is therefore necessary that the grating translates during the scanning movement.

The focal length of the instrument has been defined at 6.65 m in order to ensure the ultra high spectral resolution. This focal length value and grating groove density (4,300 groove per mm) gave a theoretical spectral resolution above 200,000, which was the goal value of the design. The 6.65 m focal length and target spectral values have risen up some constraints on the under vacuum grating scanning and translation mechanism. For example the height error of the translation have to be maintain below 0.5 μm over the 300 mm range while a scanning angular resolution of 0.05 arcsec have to be achieve. After a new approach of the under vacuum translation mechanical design and a new design of the scanning driving mechanism (Fig. 2) we install and align the new and challenging monochromator and its beamline in 1999.

Fig. 2 Inner View of Eagle Off Plane Monochromator Chamber Installed at LURE (France)

Since the completion of the installation and commissioning the monochromator has demonstrated performances above scientist expectations with a spectral resolution of 208,000 [3] (Fig. 3) and a stray light level never achieved (Fig. 4). This spectral resolution represents ever today the world record of a synchrotron monochromator.

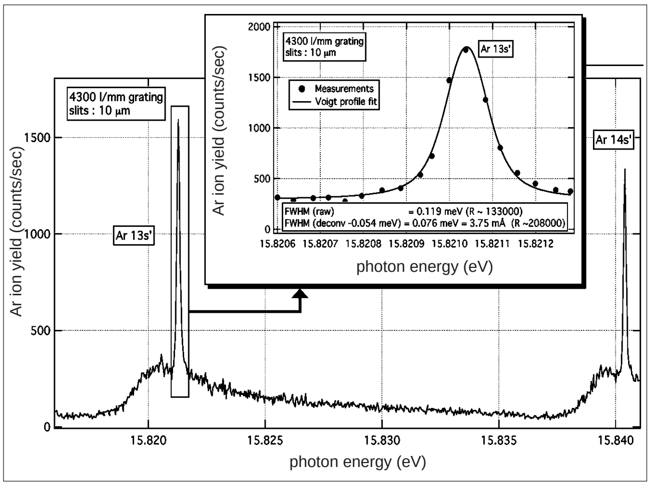

Fig. 3 Ar Auto Ionisation Spectra Demonstrating a Monochromator Spectrum Resolution of 208,000 (λ/Δλ)

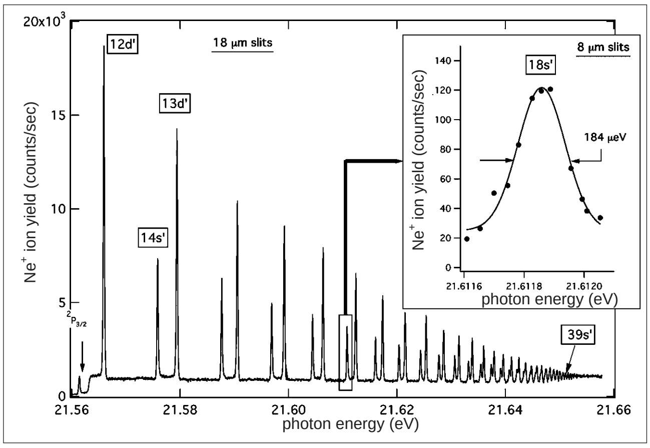

Fig. 4 Ne Auto Ionisation Spectra Demonstrating Low Stray Light Level of Monochromator

3 Compact VUV Instruments

The EUV lithography R&D programs managed by major semi conductor companies have raised up new compact VUV sources developed to have strong emission line at 13.5 nm. These sources like capillary discharge, laser induced plasma or hollow cathode do not yet present the power, repetition rate and reliability characteristics required for EUV lithography project. Nevertheless they are already providing large emission wavelength range from few nm up to few hundreds with flux and repetition rate drastically higher than penning discharge sources previously used in this domain. These new sources offer therefore an alternative to synchrotron for experiments that do not require the exceptional synchrotron characteristics. As few examples of experiments achievable with these sources we can mention EUV reflectometry, X-ray Photoemission Spectroscopy (XPS), EUV ellipsometry, fluorescence.

Thanks to our long experience in the Synchrotron monochromator designs, our diffraction grating development and production capabilities we already propose the largest range of VUV compact monochromators and spectrographs adapted to these new sources. Based on toroidal diffraction grating or similar design these instruments provide large throughput and relative high spectral resolution compare to their few hundred millimetres focal length. JY line-up includes the product models described as below for VUV application.

3.1 LHT 30

The LHT 30 was the first VUV instrument in the world designed around a toroidal aberration corrected grating. This monochromator covers the whole VUV wavelength range from 10 to 300 nm with three different gratings. Providing a spectral resolution of few tenths of nm it is the instrument of choice for most of VUV experiment types even 30 years after is development.

3.2 VTM 300

The VTM 300 (Fig. 5) designed around new generation of aberration corrected toroidal grating allows monochromator and spectrograph (flat field) operation with the same grating. A simple modification of the exit port from an exit slit to a bi-dimensional detector permits the use of the instrument as a monochromator to select an excitation wavelength or as a flat field spectrograph to characterise the emitted light of a source or sample. Covering the EUV region from 50 to 300 nm this instrument is mainly dedicated to lithography characterisation or fluorescence excitation around 100 nm where its single optics design offers an incomparable throughput.

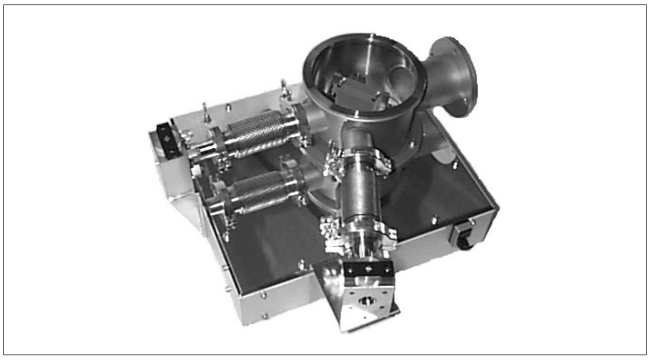

Fig. 5 Vacuum Toroidal Monograph (VTM 300)

3.3 TGS 300

VUV source characterisation is a key challenge to improve performances and reliabilities. The TGS 300 (Fig. 6) is the instrument for such application. With its three interchangeable flat field toroidal gratings this spectrograph offers a unique opportunity to perform time resolved studies over large spectral ranges (9-32 nm, 10-110 nm or 15-170 nm) with tenths of nm spectral resolution. Equipped with two-dimensional multi channel plate (MCP) detector or VUV CCD camera the TGS 300 is the most suitable instrument for source characterisation.

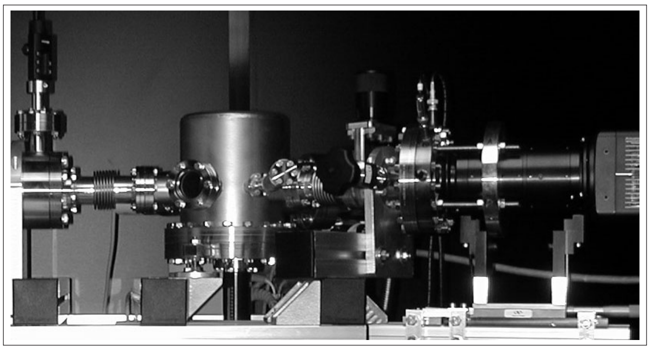

Fig. 6 Toroidal Grating Spectrograph (TGS 300)

Fig. 7 shows examples of data recordedwith the TGS 300.

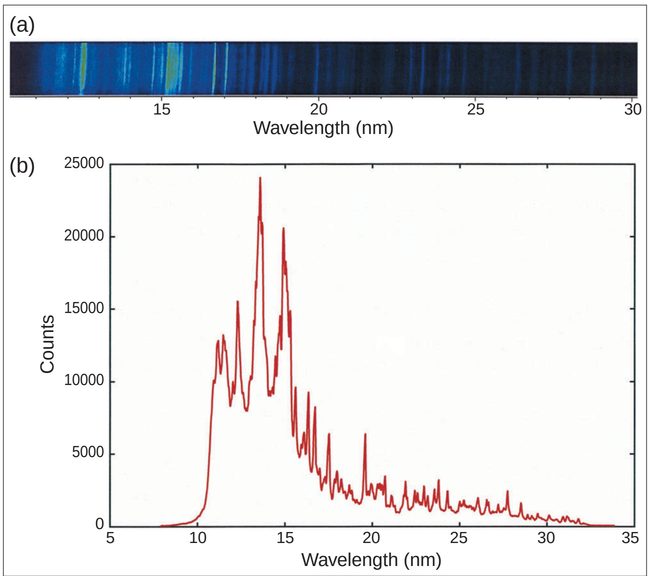

Fig. 7 Examples of Data Recorded with the TGS 300

(a) Spectral Image of a EUV Lithography Capillary Discharge Source Recorded with the TGS 300 in the Range 9.5 – 32 nm

(b) Spectrum of a EUV Lithography Capillary Discharge Source Deduced from the Image Presented Fig. 7(a)

3.4 PGM 200

Instead of the other instrument the PGM 200 (Fig. 8) is designed around a plane aberration corrected grating used in conjunction with a toroidal mirror. This slightly different design gives the opportunity to work with an exit beam parallel to the entrance one, which is crucial when space is a constraint. This is especially the case with VUV source laser generated such as high harmonics generation or plasma with gas or solid target. Similarly than the VTM the PGM is a versatile instrument that permits monochromator and spectrograph operation with the same optics.

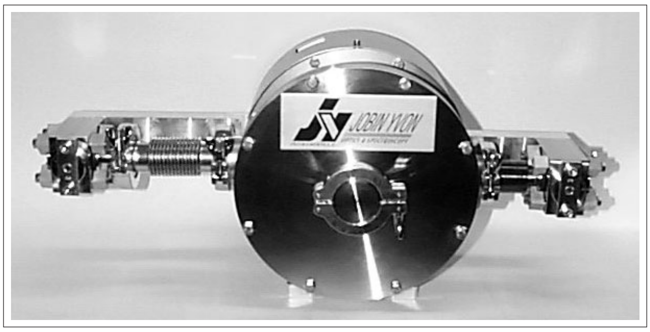

Fig. 8 Plane Grating Monograph (PGM 200)

4 Conclusion

JY has acquired over the year a large experience and renown in the designed and realisation of VUV synchrotron optics and monochromators. This has been demonstrated by some great technical successes and a reconnaissance of the world wide synchrotron community. With the JY grating team we pursue our close collaboration with the synchrotron scientists to bring new optical solution that enhance spectroscopy capability in this field but also that will benefit in the new growing field of other VUV application.

Acknowledgments

The author would like to express his thanks to the whole Jobin Yvon grating's team for their help and advices during the definition of the instruments and the wonderful performances of the optics supplied.

The VUV instrumentation in Jobin Yvon owed a lot to Dr. Lepère, who designed and developed the monochromator presented in this review.

References

[1] D. Lepère “Monochromateur à simple rotation du réseau, à réseau holographique sur support torique pour l’ultraviolet lointain”, Nouvelle Revue d’ Optique, vol. 6 (3), pp. 173 - 178 (1975).

[2] B. Deville et al. “Holographically recorded ion-etched variable-line-space gratings”, Proc. SPIE Vol. 3450, p. 24 - 35, Theory and Practice of Surface-Relief Diffraction Gratings: Synchrotron and Other Applications, Wayne R. McKinney; Christopher A. Palmer; Eds.

[3] L. Nahon *et al.* “Very high spectral resolution obtained with SU5: A vacuum ultra violet undulator-based beamline at Super-ACO”, Review of Scientific Instruments, vol. 72, number 2, February 2001, p.1320 - 1329.

Dr. Erick Jourdain

Jobin Yvon S.A.S
Gratings and OEM Division
VUV Product Manager