Improvement on a new concept of beamline delivering high purity VUV photons starting at 7.3 eV

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Abstract. We report recent improvements and performance on the Toroidal Grating Monochromator (TGM) beamline at the Laboratório Nacional de Luz Síncrotron - LNLS. Compared to normal incidence monochromators, (NIMs), TGMs provide substantially wider energy range, less resolving power and very poor higher harmonic rejection (HHR). A new concept, MIRHACILLE [1], developed at LNLS, allows reaching more than five orders of harmonic rejection (NIM gives 10%). Previously, we were not able to reach below 12 eV using MIRHACILLE. Here we report improvements extending the lower limit to 7.3 eV. Furthermore, HHR is maintained down to the lower limit using a special gas mixture, the upper limit given by 330 eV is kept.

1. Introduction
The Brazilian Synchrotron Light Laboratory was opened to users 1st July, 1997 [2]. The LNLS synchrotron source comprises a 1.37 GeV 2nd generation electron storage ring and there are 15 beamlines under operation. The TGM beamline was the first to operate at LNLS [3,4]. It was initially designed to provide high photon flux with moderate resolving power in the 12 to 310 eV energy range. Three interchangeable gratings are used. Since its opening to external users, this beamline has been extensively used in several different types of experiments ranging from photo-absorption and photo-ionization studies using coincidence electron-ion and ion-ion spectroscopies. Furthermore, it was used to: perform photoelectron and threshold photoelectron spectroscopy; study degradation of polymeric films exposed to vacuum ultraviolet light; study circular magnetic dichroism of solids; monitor the formation of bio-molecules induced by ultra-violet light. The pioneering studies of photo-ion angular distribution of laser cooled and trapped samples [5] were implemented for the first time on this beamline. This paper is intended to describe the TGM beamline current setup and characteristics. In the following section, we discuss the improvements in the monochromator mechanism critical to reach the new minimum energy. The first mirror was exchanged in order to reach even higher overall stability. Moreover, the other two mirrors had their carbon contaminations removed in house reducing months of shutdown when this needed to be performed abroad.

2. Beamline Optics
The TGM beamline is coupled to LNLS D05 (4°) bending magnet. It is the only one providing photons with energies below 100 eV. Its design aims to provide high photon flux with moderate resolving power in the 12 to 310 eV energy range. Three toroidal gratings are used to efficiently cover
this large range with the following specifications: 200, 600 and 1800 grooves/mm. Their original energy ranges are 12-35eV, 35-100eV and 100-310eV respectively. Besides the toroidal gratings, the beamline has three other focusing elements, one entrance \((f = 2650 \text{ mm})\) and two output refocusing \((f = 1000 \text{ mm})\) toroidal mirrors. Two vertical slits are used, one positioned at the entrance mirror focus and other at the grating focus. They define the resolution and the photon flux at the sample. Figure 1 shows a side view sketch of the beamline optical layout.

3. Beamline upgrading

3.1 Monochromator

Following the fundamental grating equation:

\[
\sin \alpha + \sin \beta = 10^{-6} n k \lambda
\]

where:
- \(\alpha\) (alpha) angle of incidence, in degrees;
- \(\beta\) (beta) angle of diffraction, in degrees;
- \(k\) - diffraction order; in TGM beamline we use -1;
- \(n\) - groove density; in TGM first grating the value is 200 grooves/mm
- \(\lambda\) - wavelength;
- \(10^{-6}\) – constant to use \(\lambda\), in nanometers and groove density in millimeters;

After several simulations of optics and mechanics, using Shadow and CAD, we concluded that the incidence angle, \((\alpha = 85^\circ)\), of the 200 g/mm grating could be increased and the reachable lower photon energy reduced. In fact, to get 7.3 eV, the maximum \(\alpha\) needs to be 87.7°. This was accomplished by exchanging the control driver system of the monochromator, the mechanical feedthrough, step motor and its speed.

3.2 Mirrors

The first mirror, originally made of alloy with no good thermal conductance, was replaced. The new Si-substrate mirror, allows higher thermal load removal via water-cooling [7, 8].

The second and third mirrors had their carbon contaminations removed in our site reducing months of shutdown when this needed to be performed abroad. We used 13,55MHz RF plasma (Plasma Technology SE80) with 200mTorr of Oxygen. The exposition time was 10 minutes and repeated 5 to 6 times.
Fig. 3 shows the photon flux for each of the three interchangeable gratings before and after the upgrade. Photon flux down to 7.3 eV is now available. A higher flux for each grating is obtained after the cleaning process as expected.

Figure 3. Fluxes and new minimum energy limit of the TGM beamline.

Figure 4. TGM beamline resolution measured was around 500 with 100μm slits.

TGM beamline resolution (Figure 4) was measured using Ne filter according to [1]. The obtained resolving power, given by 500, remains practically the same as before as expected.

A new concept to reach HHR (higher harmonic rejection) employing a gas mixture made of Ne, Ar and Kr was implemented. We used the lower energy grating and extended the range until 100 eV. The
results are shown in the Figure 5. The flux is smaller than showed in the Figure 3 because the spurious photons from higher order harmonics are removed by MIRHACLLE.

Figure 5. IRD AXUV100 photodiode current at the experimental station as a function of the photon energy, with the filter region filled with two different gas mixtures. The photodiode quantum efficiency was taken from the IRD supplier.

5. Conclusions
The TGM beamline at LNLS had its minimum energy reduced from 12 eV to 7.3 eV. A gas filter based on pure Neon allows harmonic contamination free measurements down to 11 (10.78) eV. In the range 8-11 eV, we used mixtures of Neon and Argon. While in the range 8-7.3 eV Krypton and Argon mixture were used. The mixture has the important advantage to eliminate the need of extra expensive pumping-capacity. The new energy range, provided by the monochromator, covers the important first ionization threshold of most biomolecules and all amino acids. Indeed, Tryptophan with the lowest IP of 7.4 eV is now within the TGM range [6].

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