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SECOND ORDER SUPPRESSION WITH GLASS FILTERS FOR UV SYNCHROTRON RADIATION CALIBRATION MEASUREMENTS

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Abstract

This development is the latest result of the cooperation between the National Laboratories of Frascati and the Department of Astronomy and Space Science of the University of Florence to improve the capabilities of the existing DXR-2 beam line at the DAΦNE-LIGHT laboratories. This collaboration has assessed a new facility in order to characterize optics and sensors in a wide spectral range (ranging from VUV to IR). Previous measurements [1] have highlighted some limitations in the present setup, as higher signal levels due to the diffracted radiation of the grating in the second order have to be removed to allow an accurate detection.
In this work a glass filter is used to remove such spurious signal present in the spectral region with $\lambda > 360$ nm. The characteristics of the filter and its application to the optical system used to measure the sensitivity of a diamond-based photoconductor have been discussed.

1 INTRODUCTION

The unique capabilities of the synchrotron radiation, in terms of wide and continuous spectral range are well known. In particularly, due to the very high current circulating in DAΦNE, the storage ring complex of the National Laboratories of Frascati (LNF), all three existing beamlines provide a very intense synchrotron radiation emission from the IR to the soft x-ray region. [2]

The scientific agreement between LNF and the Department of Astronomy and Space Science of Firenze (DASS) recently started, is aimed to evaluate the feasibility and eventually to develop a general purpose facility to make available all of these unique SR characteristics for sensors testing and optics characterization.

A present limitation to the exploitation of the UV-VIS radiation at the DXR-2 beamline is related to higher signal levels introduced by the radiation diffracted in the second order. In particular, this effect is important measuring the spectral response of detectors based on wide bandgap materials, as diamond. Such detectors present a cut-off wavelength corresponding to the bandgap energy. The radiation with energy lower than the bandgap does not interact with the material: diamond photodetectors show nine orders of magnitude between sub-bandgap and over-bandgap signals (visible blindness). So, testing the sensitivity of such devices in the visible, even a small amount of spurious photons with energy greater that the bandgap can give significant photocurrent signals [1].

2 INSTRUMENTAL SETUP

The DXR-2 beam line can provide radiation in the energy region between 1.55 eV and 1 keV. These limits are respectively imposed by the small horizontal acceptance angle and the maximum energy of reflected photons at 2.2^{o} by a gold coated plane mirror. [2] Actually, the spectral range is further limited, at higher energies, by the sapphire window at the end of the vacuum line and by several reflections in air before the grating monochromator. These reflections are needed to deviate and focus the radiation beam on the entrance slit of the monochromator, but they introduce an intensity cut-off at 190 nm. The monochromator is a Czerny-Turner optical configuration f/5.3 with a focal length of 460 mm (Jobin-Yvon mod. HR460MST2-2XM). It is equipped with a 2400 line/mm holographic grating, optimised for 250 nm, which covers the 190-600 nm spectral range with a spectral resolution 0.1-0.3%.

The radiation intensity at each wavelength was calibrated with a silicon photodiode. The current signal was amplified and converted into a voltage signal by a Keithley 427 Current Amplifier (with maximum gain of 10^{9} V/A) and then recorded by a digital multimeter. The diamond detector current signal was measured with a Keithley 6517A electrometer making use, for the device bias, of its intrinsic voltage source up to 1000 Volts.

3 EXPERIMENTAL

Using the UV radiation at the DXR-2 beamline in the 190-600 nm spectral range, we have to take into account the contribution from the diffracted radiation in the second order. Owing to such effect, the radiation at wavelength 190-300 nm in the second order is superimposed to the 380-600 nm spectral range. Since diamond photodetectors are much more sensitive at wavelengths shorter than 225 nm, even very low fluxes of photons at such wavelengths mixed to higher fluxes of photons at sub-bandgap energies can give a significant contribution [1].

To avoid this problem the use of high-pass filters was proposed. In this report the study of a possible high-pass filter was reported, showing the results of spectrophotometric tests using synchrotron radiation and the application during the characterization of a diamond photoconductor.

4 THE FILTER STUDY

The preliminary study of the long-wave-pass filter was made in collaboration with the National Institute of Applied Optics (INOA) in Firenze. A high-quality low-cost glass filter with high transmissivity in the visible and near UV spectral regions was firstly selected.

The external transmittance (T_λ), defined as the convolution of the reflectivity (about 4% on both surfaces) and the transmittance of the material, can be calculated as the ratio between intensity of the monochromatic beam exiting from the filter (I_λ) and the intensity of the impinging beam ($I_{\lambda o}$), as shown in the following formula:

$$T_\lambda = \frac{I_\lambda}{I_{(\lambda o)}}$$

The transmittance of the filter was measured using a Perkin Elmer Lambda 900 spectrophotometer operating in the range between 180 nm and 550 nm with a resolution of 1 nm. The transmittance curve is shown in Fig. 1.

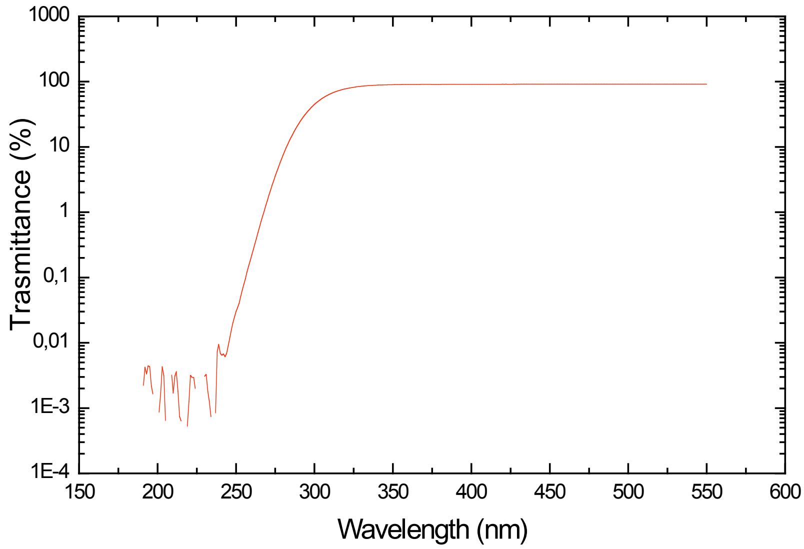

FIG 1. Transmittance spectra of the glass filter measured at DASS in Firenze.

Using these data, a cut-off wavelength of 263 nm was calculated [the cut-off wavelength of a filter is defined as the wavelength at which the signal is reduced by a factor 1/e]. At wavelengths shorter than 254 nm the signal is 5 orders of magnitude less than at longer wavelengths where the mean transmittance is always greater than 90%. For this reason, this glass filter was considered suitable to remove the contribution due to radiation in the second order at the exit slit of the existing monochromator.

5 TEST OF THE FILTER AT THE DXR-2 BEAM LINE

After the installation in the optical setup of the LNF beam line, the long-wave-pass filter was tested. Since the exit window of the SR vacuum beam line and the entrance slits of the monochromator can not be removed, some mirrors are required to deviate and collimate the

beam onto the device. To avoid the stray light due to the radiation in the second order, we placed the filter on the entrance slits. In this geometry the beam does not impinge perpendicularly to the filter, so that the amount of the reflected beam and the optical thickness change. However, because SR activity is parasitic, the orbit parameters of the electron circulating are often adjusted and then the exit position, the impinging angle and the beam intensity can slightly change, the beam calibration is frequently required.
The beam absolute intensity as a function of wavelength was measured in two different sessions, i.e., in two different days in order to check also the reproducibility. Afterwards, the filter was placed in its position and the beam intensity again measured. Comparison of data is reported in Fig 2.

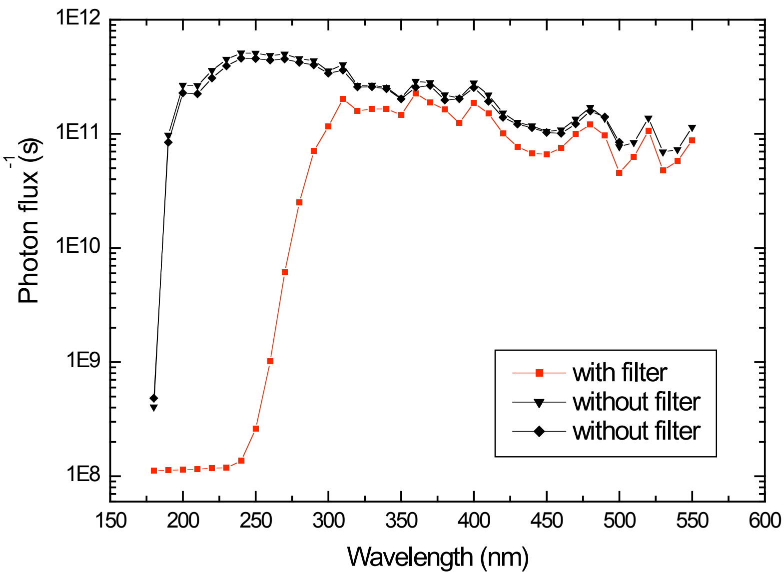

FIG 1. The photon flux measured at the DXR-2 synchrotron beam line as a function of wavelength. Two different data set, performed in different days, are reported (black curves). The measurement of the same photon flux performed introducing the glass filter is also shown (red curve).

The difference between the spectra measured with and without the filter is due to two different reasons. Firstly, the red curve in Fig.2 represents the convolution of the spectral intensity distribution of the photon beam with the transmittance of the filter. This suppresses the intensity at shorter wavelengths but also reduces by 10% the mean transmittance value at longer wavelength due to the 90% transmittance of the filter. Furthermore, since the radiation beam is not perpendicular to the filter, the reflected radiation and the optical thickness increases, thus lowering the measured transmittance. The loss of photons in the second order between 360 nm and 600 nm must be also considered. To verify that SR data are comparable with the measurements previously performed in Firenze, the transmittance of the filter was calculated using the data obtained with SR. The comparison between the two curves is reported in Fig. 3. The two measured transmittance spectra are slightly different at longer wavelengths and this is probably due to the effects previously addressed. Furthermore, the higher values measured with SR in the region below the cut-off wavelength are likely due to the lower sensitivity of the instrumentation: the minimum detectable signal is two order of magnitude higher with SR than with an UV lamp after the lower accuracy in the silicon photodiode photocurrent measurement.

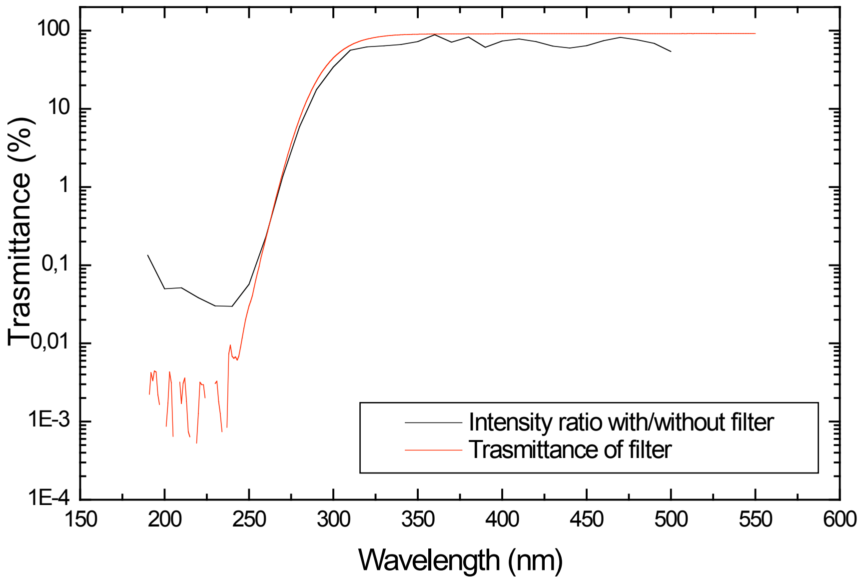

FIG 2. Comparison between the external transmittance of the filter measured with an UV lamp and that calculated from the SR data at LNF.

6 FIRST APPLICATION

The first application of the glass filter was the calibration of the visible blindness of a diamond UV photoconductor. This device was based on a commercially available High Pressure High Temperature (HPHT) 1b diamond crystal, produced by Sumitomo. It was cut and mechanically polished to {100} within 4°, with final 4 × 4 mm^2 size and thickness of 350 μm. The sample appears yellowish, due to the 100 ppm nitrogen concentration, but it is optically transparent. A couple of 2 × 2 mm^2 interdigitated coplanar gold contacts were deposited on one of its surfaces. Contact pitch and width are 20 μm. The sensitivity of such device was measured in the 200-500 nm spectral range. In the spectral region from 360 nm to 450 nm the radiation in the second order generates a spurious signal bump [1]. Two series of measurements were performed with and without the glass filter. The external quantum efficiency, calculated from such measurements, is plotted in Fig. 4. By interposing the filter, we were able to remove the strong SR intensity bump caused by the grating in the second order, as expected.

7 CONCLUSIONS

We presented the results obtained using an optical filter developed by DASS in cooperation to INOA to remove spurious signals due to SR radiation diffracted by the grating in the second order and overlapping the visible portion of the spectrum. This simple high-quality low-cost glass filter was used as deep UV filter. A complete assessment of such filter was performed first at DASS in Firenze and then at the LNF using the UV radiation emitted by DAΦNE. A first application, during the characterization of a diamond detector was described.

This work extends and completes the feasibility study that was performed in order to expand the capabilities and the spectral range of the DXR-2 beam line from the visible to the deep UV.

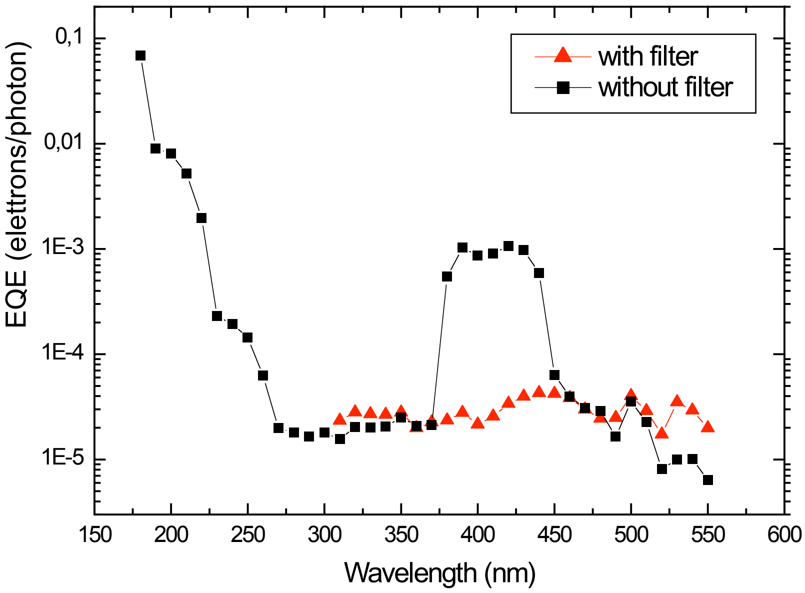

FIG 4. Sensitivity spectra of the diamond based detector. The two data set are performed without interposing the filter (black squares) and with the filter (red up triangles).

References

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