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OPTICAL PROPERTIES BEHAVIOR OF THREE OPTICAL FILTERS AND A MIRROR USED IN THE INTERNAL OPTICAL HEAD OF A RAMAN LASER SPECTROMETER AFTER EXPOSED TO PROTON RADIATION

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The Raman Laser Spectrometer is one of the ExoMars Pasteur Rover's payload instruments that is devoted to the analytical analysis of the geochemistry content and elemental composition of the observed minerals provided by the Rover through Raman spectroscopy technique. One subsystem of the RLS instrument is the Internal Optical Head unit (IOH), which is responsible for focusing the light coming from the laser onto the mineral under analysis and for collecting the Raman signal emitted by the excited mineral. The IOH is composed by 4 commercial elements for Raman spectroscopy application; 2 optical filters provided by Iridian Spectral Technologies Company and 1 optical filter and 1 mirror provided by Semrock Company. They have been exposed to proton radiation in order to analyze their optical behaviour due to this hostile space condition. The proton irradiation test was performed following the protocol of LINES lab (INTA). The optical properties have been studied through transmittance, reflectance and optical density measurements, the final results and its influence on optical performances are presented.

I. INTRODUCTION

ExoMars 2018 mission is an ESA-Roscosmos collaboration and will deliver an European rover and a Russian surface platform to the surface of Mars. The ExoMars rover will search for signs of life. It will collect samples with a drill that is designed to extract samples from various depths. Once collected, it is delivered to the rover's analytical laboratory, which will perform mineralogical and chemistry determination investigations. The Raman Laser Spectrometer (RLS) forms part of one of the instruments included in ExoMars rover. The RLS is made of three main units: the Spectrometer Unit (SPU), Internal Optical Heat (IOH) - and the Instrument Control and Excitation Unit (ICEU) (Fig.1) [1, 2].

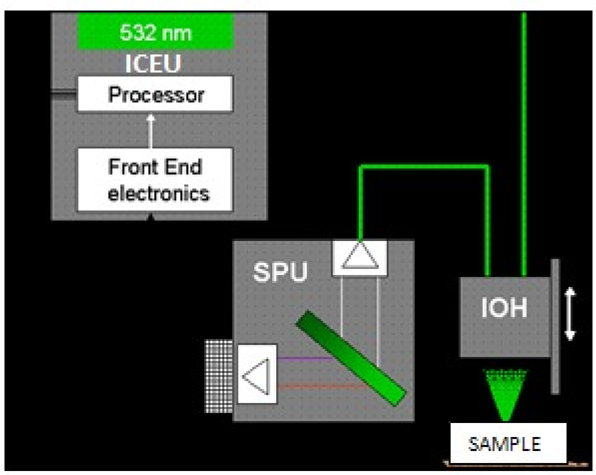

Fig. 1. Functional diagram of RLS

The sample is illuminated through the lens of IOH with laser light from the green laser diode (531.45nm) housed in the ICEU. The Raman signal produced by the sample will be collected through the internal optical head and led by an optical fiber to the spectrometer SPU.

The Internal Optical Head consist of two optical paths; the excitation path that goes from the laser to the sample and the collection path that collect the Raman signal emitted by the sample, as shown in figure 2.

This paper describes the optical properties behaviour of IOH filters and mirror after proton radiation test in order to validate the response of these optical elements to ExoMars environment.

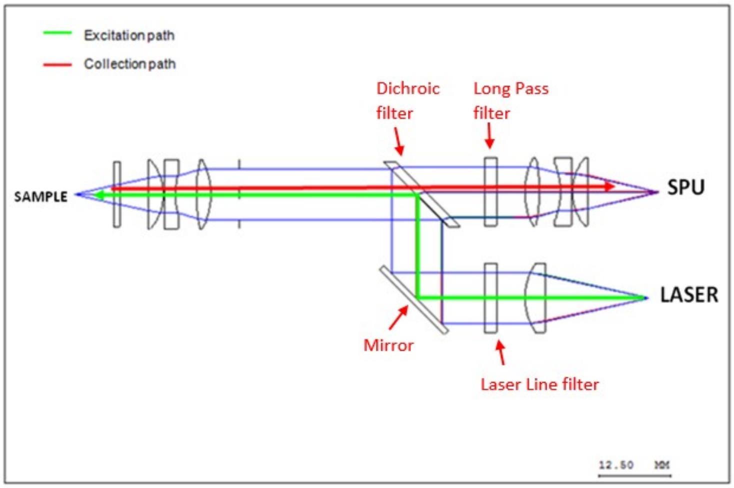

Fig. 2. IOH optical design

II. OPTICAL ELEMENTS DESCRIPTION

A. Laser Line filter

The Laser Line filter is necessary to ensure that only enter to the system the excitation wavelength (532nm). This filter is ***532 nm MaxLine laser clean-up filter*** from ***Semrock*** Company. The substrate is fused silica; it is coated with hard dielectric layers.

The transmission at 532nm is greater than 90% and the FWHM Bandwidth is 2nm to eliminate the optical noise from non-lasing lines and spontaneous emission. The angle incidence of this filter is 0 ± 2º. The optical densities (OD) of the filter blocking bands are as follows:

- Blocking Band 1: 446.5 – 526.7 nm OD > 5
- Blocking Band 2: 489.4 – 524 nm OD > 6
- Blocking Band 3: 540 – 585.2 nm OD > 6
- Blocking Band 4: 537.3 – 699.4 nm OD > 5

The Laser Line filter physical size is 13mm diameter and 2 mm thickness.

B. Mirror

The function of the mirror is to reflect the beam from the Laser Line Filter. This mirror is ***350 – 700 nm Semrock General Purpose Mirror*** from ***Semrock*** Company. The substrate is fused silica; it is coated with hard dielectric layers.

The reflection band is better than 98% from 350nm to 700nm. The angle of incidence is 45.0 ± 1.5º.

The mirror physical size is 16mm diameter and 1 mm thickness.

C. Dichroic filter

The Dichroic filter reflects the laser beam from the mirror and transmits the Raman signal from the sample. This filter is ***Dichroic – Long Pass Filter (Laser Lines)*** from ***Iridian Spectral Technologies*** Company**.** The substrate is fused silica from CORNING 7980 class 0, grade A; it is coated with hard dielectric layers.

The angle incidence is 45º. The transmission average is better than 95% from 535 to 676nm. The absolute reflection is better than 95% from 531.5 to 532.5nm.

The Dichroic filter physical size is 36.2x25.2mm and 2 mm thickness.

D. Long Pass filter

The function of the Long Pass filter is to block the Laser Line signal in the collection path to avoid the Rayleigh scattering. This filter is ***Edge – Long Pass Filter (Nano – Edge)*** from ***Iridian Spectral Technologies*** Company. The substrate is fused silica from CORNING 7980 class 0, grade A; it is coated with hard dielectric layers.

The OD of the filter blocking level is 6. The filter cut-off is 38 cm^{-1} (~1nm), so it is possible to access to low frequency Raman modes. The transmission is nominally better than 90% from 535 to 1200nm. The angle of incidence is 0º.

The Long Pass filter physical size is 13mm diameter and 3 mm thickness.

III. RADIATION ENVIRONMENT AND TEST SET UP

The proton irradiation tests were performed at RADEF facilities (Jyvaskyla, Finland) in January, 2014. Proton radiation produces non-ionization damages; it means the energetic particles induce nuclear interactions with material atoms which cause solid lattice defects. Those accumulated lattice defects are known as Displacement Damage (DD) [3].

The effects produces by the DD are relation to the Non Ionizating Energy Loss, NIEL, so in order to evaluate the possible DD effects of the radiation environment on IOH optical elements a NIEL equivalent to 10MeV proton energy for the mission is needed. Figure 3 shows the required data for ExoMars mission.

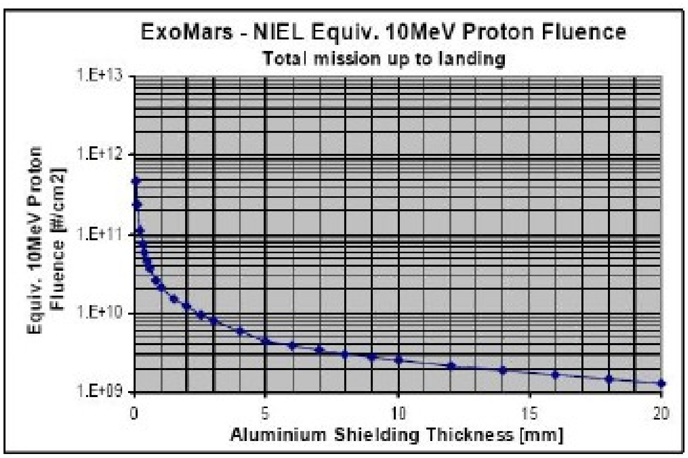

Fig. 3. Equivalent 10 MeV total mission protons fluence up to landing vs Al shielding

Proton Irradiation tests were performed in five parts, it is shown below the irradiation steps and fluences:

Table. 1. Proton irradiation test fluence steps values

Step	**Step Fluence (p^+/cm^2)**	**Accumulated Fluence (p^+/cm^2) (Normalized to 10MeV)**
01	1E09	1E09
02	4E09	5E09
03	5E09	1E10
04	4E10	5E10
05	6E10	1.1E11

The total amount of optical elements that were characterized was 12 samples (3 samples per optical element).

For that test, a mechanical structure was specifically designed to support the samples in order to allow an uniform irradiation. The Test Sample Holder (TSH) was made of delrin (Polyoxymethylene) and was composed by two plates screwed by means of 4 M4.

The test was performed using two different TSH; one for the laser line filters, Long Pass filters and mirrors and the other for the dichroic filters. The next figures 4 and 5 show the position of the filters and mirrors on the two different TSHs. The position of the optical elements; filters and mirror, between each step of proton radiation was always the same.

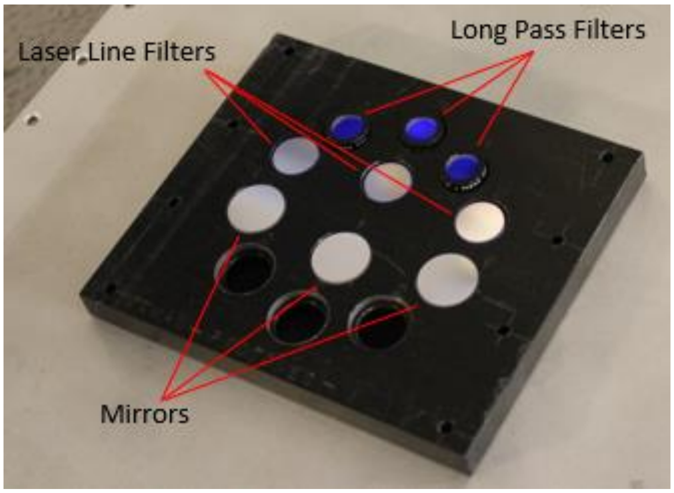

Fig. 4. Distribution of the Laser line filters, Long Pass filters and mirrors on the TSH.

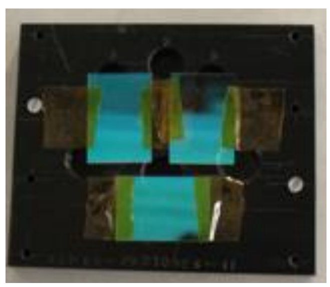

Fig. 5. Distribution of the Dichroic filters on the TSH.

IV. EXPERIMENT RESULTS

The objective of analyzing the optical filters and mirror is to know the optical properties behaviour under space hostile environmental conditions such as proton radiation. Optical properties of the optical elements were studied before and after they exposed to space conditions. A change of the material optical constants means the degradation of the optical performances of the elements. Optical properties degradation will be obtained by comparison of the optical data measured before and after test.

All optical measurements, before and after the test were carried out at room conditions, temperature and pressure. The optical characterization consisted of performing transmission, reflectance and optical density measurements. The optical pre-characterization was performed before the exposition to space conditions at LINES (INTA) laboratory. Immediately after the end of the test, the post-characterization was done at RADEF facilities.

A. Transmission measurements

Transmission measurements for the optical elements before and immediately after each step of proton radiation have been performed using a portable HR 2000- UV NIR Ocean Optics High resolution Spectrometer. The Laser Line Filter, the dichroic filter and the Long Pass Filter transmittance have been performed.

Figure 6 below shows the transmission spectrums of one Laser Line Filter sample before and after each step of proton irradiation. The influence of the proton irradiation on the Laser Line Filter transmission can be considered negligible. The transmission value (%) for the laser wavelength (532nm), before proton radiation is 56±2 and after the maximum proton accumulated fluence, 1.1E11p$^+$/cm^2, is 59±2. Note that the transmittance values are lower than the filter specification (>90% at 532nm). It is because of the fact that the spectral resolution of the High resolution spectrometer (<1nm) is not enough to resolve all the point of the curve taking into account that the bandwidth of the filter is 2nm.

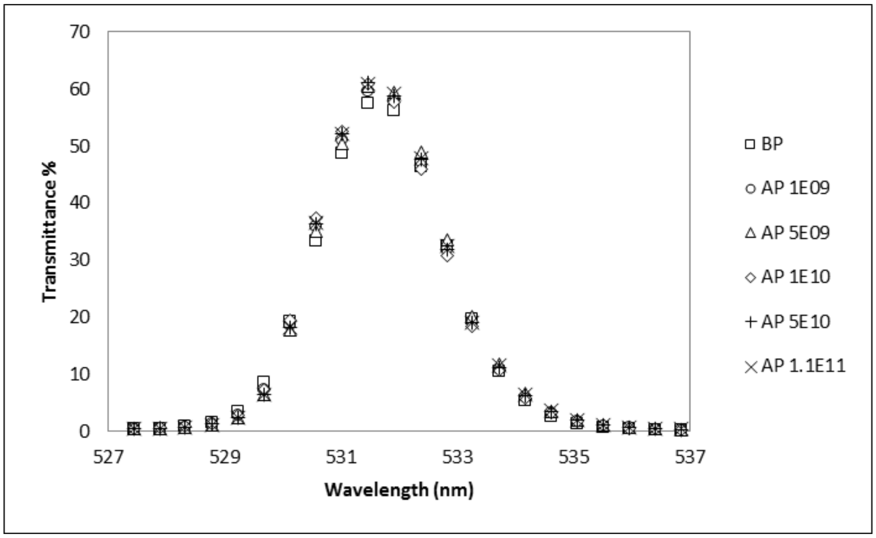

Fig. 6. Transmittance of a Laser Line filter before and after proton radiation according to the different accumulated fluence* (p$^+$/cm^2)

(*) BP: Before Proton Radiation / AP: After Proton Radiation

The next Figure 7 shows the transmission spectrum of one dichroic filter sample before and after each step of the proton irradiation. The variation of the dichroic filter transmittance after proton irradiation is inside the measurement uncertainty. The transmission value (%) before proton radiation at 582nm, wavelength inside the work spectral range, is 46±5 and after the maximum proton accumulated fluence, 1.1E11p+/cm2, is 53±5.

The dichroic filter works at 45º, but these transmission measurements were measured with an angle of incidence of 0º. This is not relevant to analyze the optical properties changes of the dichroic filter due to the proton radiation, because if any transmission degradation occurs at 0º, also it will occur at 45º.

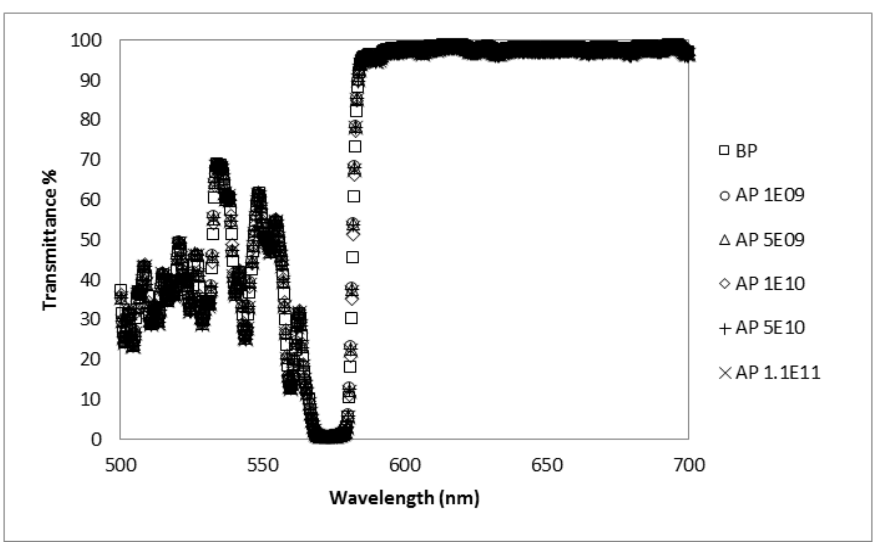

Fig. 7. Transmittance of a Dichroic filter before and after proton radiation according to the different accumulated fluence* (p$^+$/cm^2)

The next Figure 8 shows that the transmission spectrum of one Long Pass filter sample before and after each step of the proton irradiation not change. The transmission value (%) before proton radiation at 535nm, wavelength inside the filter work spectral range, is 97±2 and after the maximum proton accumulated fluence, 1.1E11p+/cm2, is 96±2.

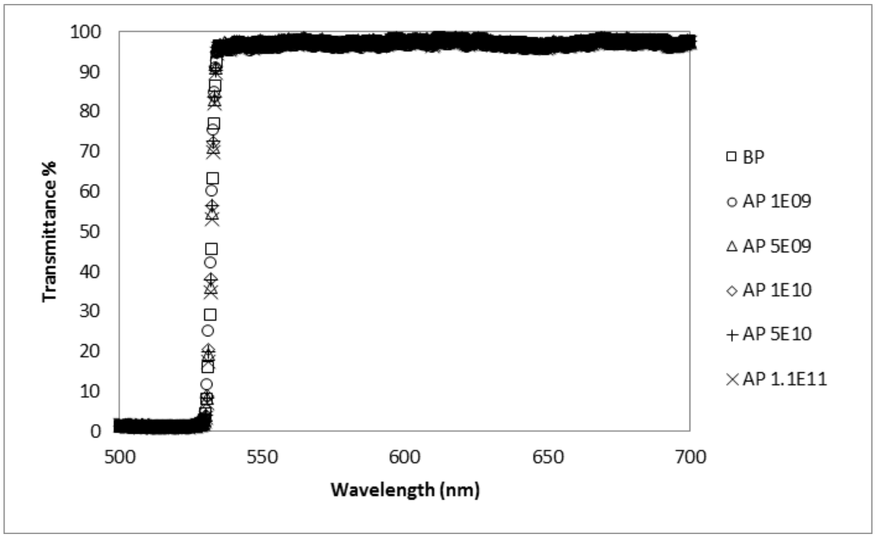

Fig. 8. Transmittance of a Long Pass filter before and after proton radiation according to the different accumulated fluence* (p^+/cm^2)

B. Reflectance measurements

Reflectance measurements have been performed before and after one week of the end of the proton irradiation test using a Perkin-Elmer Lambda 850 Spectrophotometer with a Universal Reflectance Accessory (URA) at LINES (INTA) laboratory. The measurements have been performed with 1 nm optical resolution and 45º of angle of incidence. The reflectance measurements have been performed at the mirror and dichroic filter.

Figure 9 shows the reflectance spectrum as function of the wavelength of one mirror sample before and one week of the end of the proton irradiation test. The variation of the reflectance due to the proton radiation for the whole spectral range is negligible. The reflectance value (%) before proton radiation at 532nm is 98.5±0.2 and one week after the maximum proton accumulated fluence, 1.1E11p^+/cm^2, is 98.5±0.2.

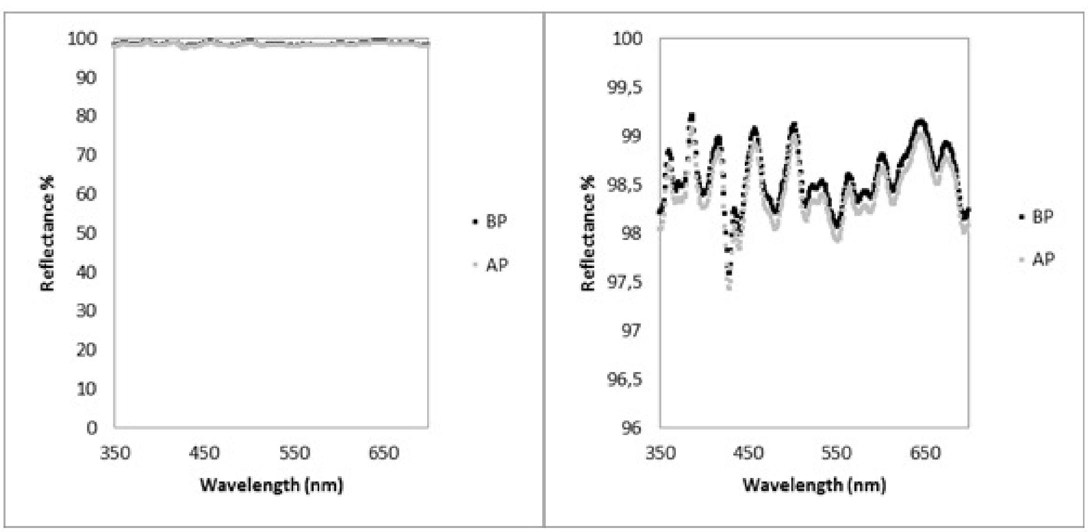

Fig. 9. Reflectance of a mirror before and one week after 1.1E11p^+/cm^2 accumulated proton fluence *

Figure 10 shows that the reflectance spectrum of the dichroic filter before and one week of the end of the proton irradiation is the same. The reflectance value (%) before proton radiation at 532nm, a representative wavelength inside the work spectral range, is 75±1 and one week after the maximum proton accumulated fluence, 1.1E11p$^+$/cm^2, is 77±1. Note that the reflectance values are lower than the filter specification at 532nm (R>95% from 531.5 to 532.5nm. Taking into account that the curve slope of the filter from the minimum value to maximum value is 8nm and the spectral resolution of these measurements is 5nm, the instrument not resolves all the points of the curve.

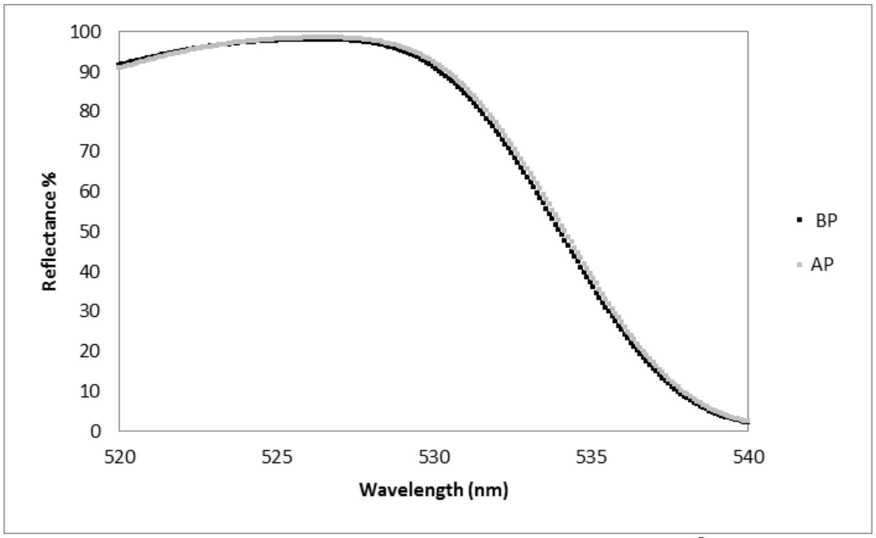

Fig. 10. Reflectance of a Dichroic filter before and one week after 1.1E11p$^+$/cm^2 accumulated proton fluence *****

C. Optical Density measurements

The optical density measurements have been performed at the Laser Line and Long Pass filters. These measurements have been performed before and after one week of the end of the proton radiation test using a Perkin-Elmer Lambda 850 Spectrophotometer at LINES (INTA) laboratory. The measurements have been performed with 1 nm optical resolution and for an angle of incidence of 0º. Given that obtaining measures with low intensity is very difficult, for these measurements is necessary to place 2.5 optical density filter to take the 100% reference light closer to measurement values. Thus, we can obtain measures with high optical densities.

The next Figure 11 shows the Optical Density spectrum of the Laser Line filter before and one week of the end of the proton irradiation. Variations after proton irradiation are inside the measurement uncertainty. The optical density value before proton radiation at 524nm is 6.2±0.5 and one week after the maximum proton accumulated fluence, 1.1E11p+/cm2 is 6.3±0.5. The optical density value before proton radiation at 540nm is 6.2±0.5 and one week after 1.1E11p+/cm2 proton accumulated fluence is 6.4±0.5.

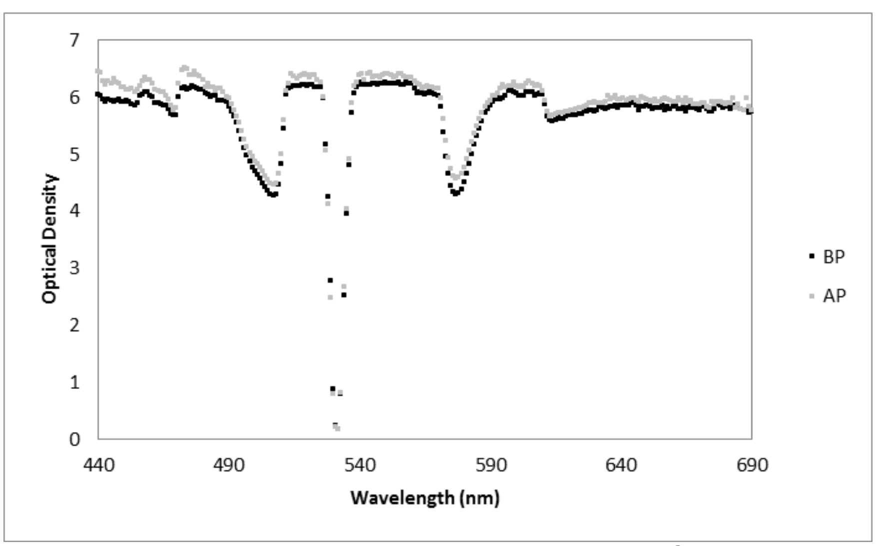

Fig. 11. Optical Density of LL01-1 before and one week after 1.1E11p$^+$/cm^2 accumulated proton fluence *

The next Figure 12 shows the Optical Density spectrum of the Long Pass filter before and one week of the end of the proton irradiation. The optical density variations due to the proton irradiation are negligible. The optical density value before proton radiation at 531nm is 2.9±0.2 and one week after the maximum proton accumulated fluence, 1.1E11p+/cm2 is 2.5±0.2. Note that the optical values are lower than the filter specification at 532nm (OD 6 at 532nm). It is because of the fact that the spectral resolution of the Perkin-Elmer Lambda 850 Spectrophotometer used in these measurements (1nm) is not enough to resolve all the point of the curve taking into account that the cutoff of the filter at 532nm is 1nm ($38cm^{-1}$).

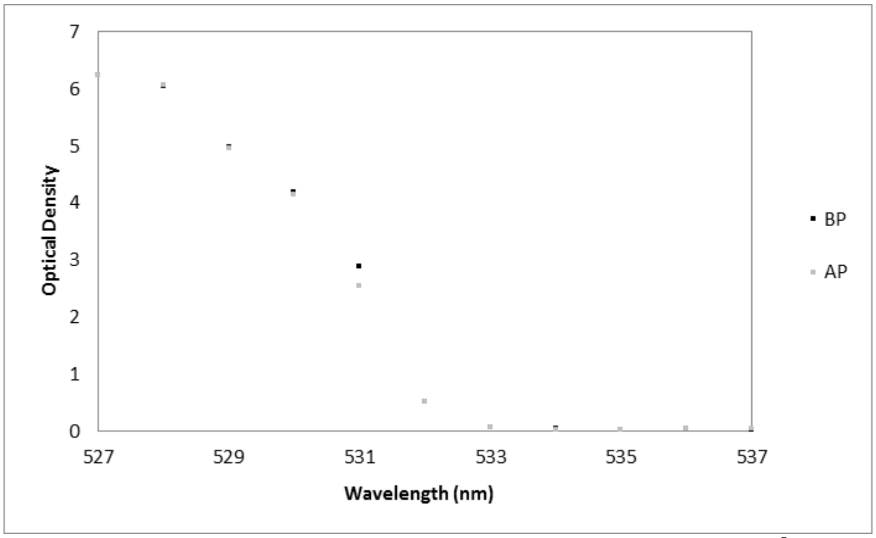

Fig. 12. Optical Density of a Long Pass filter before and one week after $1.1E11p^{+}/cm^{2}$ accumulated proton fluence*

V. CONCLUSIONS

Optical properties of four commercial optical elements have been analyzed after they were exposed to proton radiation.

Transmittance and optical density variations of the ***532 nm MaxLine laser clean-up filter*** due to the proton radiation are inside measurements uncertainty.

Reflectance of the ***350 – 700 nm Semrock General Purpose Mirror*** has not affected by proton radiation.

Dichroic – Long Pass Filter (Laser Lines) transmittance and reflectance variations are inside measurements uncertainty.

Variations induced by proton radiation on transmittance and optical density of the ***Edge – Long Pass Filter (Nano – Edge)*** are negligible.

V. ACKNOWLEDGMENTS

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