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Plan for the protection of Target Imaging Systems Mirrors against Corrosive Environment

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Abstract

The production of corrosive agent, like ozone and acids like nitric acid in accelerator vacuum chambers has been found and measured in many accelerators. The risk of having formation of nitric acid in the target monolith area is rather high. Corrosion at several facilities like SNS, J-parc and PSI has been reported and the phenomena starts to be understood. In this document, we draw a plan to investigate a possible coating protection for the mirrors of the Target Imaging Systems in the PBIP. The objective is to identify a protective coating layer which allows the mirrors reflectance and surface quality to remain within the specification for the lifetime of the PBIP slices. A series of test to understand and qualify the mirror protective coatings will be carried out, in order to provide a solution to this potential problem before ESS enters its operational phase.

Contents

1 Introduction

One of the main corrosive agent produced in moist air atmospheric environment in presence of ionization radiation is nitric acid[1, 2, 3]. A typical number for the production of nitric acid in radiation environment and in particular with protons [4] is the radiolytic yield of nitric acid (G-value). Experimental[4] evaluation shows G≈ 1.46 (molecules per absorbed 100eV). A rapid calculation using G lead to a production of 2.2 moles of nitric acid in a year. For that calculation we have been taking into account the stopping power of 1 mbar of moist air for a 2 GeV proton beam, 2 m of air thickness, 5000h of beam at 5MW:

- Density of moist air at 1 mbar: $\rho = 1.204 \times 10^{-9}$
- Energy lost by 2 GeV protons in moist air: $\Delta E = 364\,\mathrm{eV}$
- Number of protons per pulse: $N_{pr} = 10^{15}$
- number of pulses per year: $N_p = 252 \times 10^6$
- Avogadro number: $N_a = 6.0210^{23}$

The production of nitric acid in moles is then:

$$N_{HNO3} = G\,\frac{\rho\,\Delta E\,N_p\,N_{pr}}{N_a} = 2.2 \qquad (1)$$

This is a large enough number to anticipate and expect rapid corrosion on all the mirrors in the PBIP.

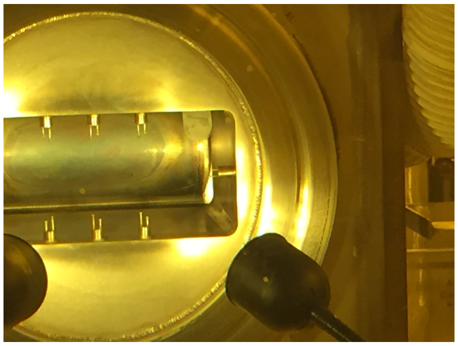

Figure 1: Image of the first mirror of SNS target imaging system, taken on the hotcell after been removed from its plug. The mirror in the top right corner is totally corroded.

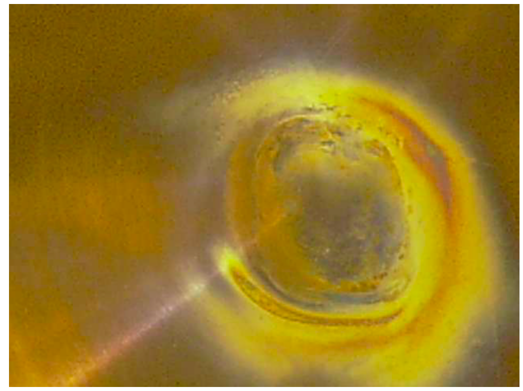

Figure 2: T2K Beam Window replaced after 1.8 DPA. Visual inspection shows corrosion.

The analysis above is rather simplistic and needs some further verification. For instance, water vapor is estimated here to be of the order of 1%, and the saturation process is not considered. However, a fraction of a mole of nitric acid is already bringing an issue to the mirrors of the Target Imaging Systems, as it is observed at SNS and at KEK, and shown in the Fig. 1 and 2 respectively. In both cases, the atmosphere is 1bar He, with high purity, and in both cases, air and/or water leakage is present.

From these examples, it is clear that there will be an issue with nitric acid production, even more if the environment is air and not a neutral gas. Therefore a solution to retard or prevent the corrosion of the surface of the mirrors has to be found, before the facility enters in production phase.

2 Requirements and Planning for a Solution

The requirements for a solution to the nitric acid corrosion are derived from the requirement on the imaging systems. mainly, the lifetime of the system in the PBIP is 2 years. Therefore the solution should retard the corrosion and maintain the performance of the optical systems for 2 years.

Corrosion on the surface will affect the mirror properties as soon as the corrosion layer is thicker than 20 to 40 layers of atoms. So the immediate solutions would be to find a reflective metallic material that is resistant to nitric acid, or to deposit a protective layer on the mirror coating.

Some metal are resistant to nitric acid, for instance, gold or metals in the Platinum group. Their optical properties should be investigated and their nitric acid resistance too.

The other possibility would be to protect the mirror coating with a layer, transparent to the wavelength range over which the imaging will be done, and resistant to nitric acid. Our immediate proposition is SiO_2 layer, which is commonly used as a protective layer for Ag and Al mirror coatings. The SiO_2 layer resistance to nitric acid remains to be demonstrated. The chance is probably high. Indeed, silica glass are resistant to most acids, and in addition, the production of silicon oxide consist of oxidation of silicon with nitric acid.

3 Protective mirror coating down-selection

All the mirrors in the target atmosphere must withstand its environment. For instance, the closest mirror to the proton beam must withstand temperature fluctuations from 20°C to 100°C degrees and intense radiation.

The ideal protective coating should:

1. Have an excellent reflectance in the range of the luminescent coating emission.
2. Survive in the corrosive atmosphere.
3. Not be compromised by the temperature fluctuations.
4. Not be compromised by the radiation.

A series of tests will be done on selected standard industrial mirrors; tests involving exposition to nitric acid and radiation. After each test, the reflectance of the mirror will be measured and compared to initial condition. In addition, surface quality may be degraded by a thin layer of corrosion. The proposed test is to qualify a test-target image through the mirror.

Assuming the cause of the corrosion is nitric acid, the first test on any protective coating should be to make sure it survives concentrated and diluted nitric acid. This will be tested in Oslo/ESS as soon as mirror samples are available. Making sure the coating can withstand temperature fluctuations can also be done in Oslo.

Additional irradiation exposure tests will be carried out, but we need more input to understand relevant doses to determine which beam facilities can be used for irradiation.

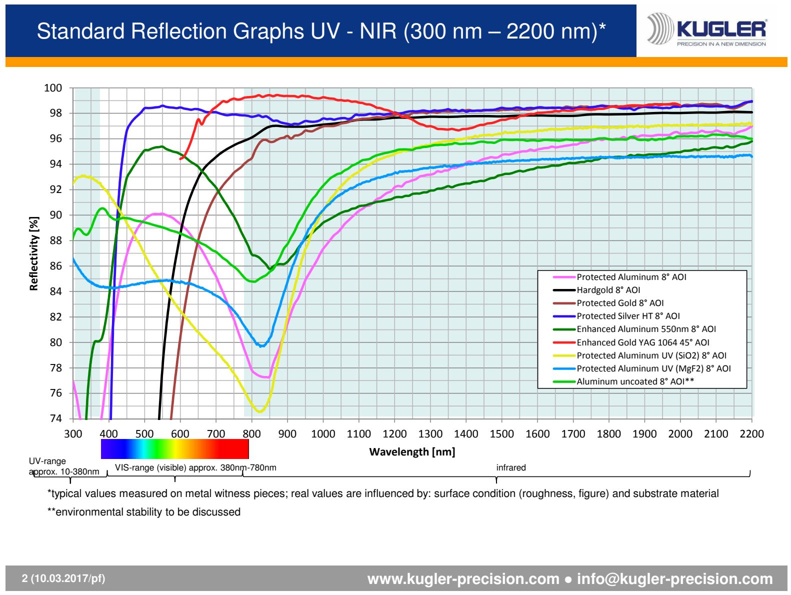

Figure 3: Reflection curves of coatings provided by Kugler

4 Candidate coating

Nitric acid will corrode most metals, with the exception of gold and metals in the Platinum group. Gold coated mirrors are common, as gold has excellent reflectance above 600nm.

Another option is a thin transparent protection coating. SiO_2 is a common protective coating, which should withstand most acids, with the exception of hydrofluoric acid.

Mirror samples from Kugler have been ordered with the following coatings:

- SiO_2 protected aluminium: Very good reflectance for blue and UV.
- SiO_2 protected silver: broad band, excellent reflectance down to 450nm.
- Unprotected gold: Very good reflectance in red and IR.

Reflection curves for the various coatings are listed in Figure 3.

5 Collaboration with SNS

Recent events at SNS showed a rapid degradation of the first mirror of their target imaging system. Investigation concluded that the loss of the imaging system is corrosion and most probably nitric acid corrosion. A collaboration with SNS is started to investigate and assess protective coatings resistance to nitric acid.

The SNS plan is to expose different samples at Fermilab with radiation and air [Wim Blokland, private communication]. They have small mirrors with gold, silver, aluminum coatings, and protected versions of those, including SiO_2. The objective is to tests resistance of the mirrors in similar environment condition as at SNS. The mirrors will be exposed to radiation in an open container in presence of controlled moist air. Their schedule is not clear yet.

6 Impact on schedule

It is recommended by the vendor[1] to add the coating to the mirror at the time of production. This means that the procurement of the mirrors should not start until a choice for protective coating has been made. This could lead to a delay in the schedule. In addition, the lead time to manufacture the first mirror is 7 month. The beam on target is planned to be now at the end of 2020, but the installation in the target will happen earlier than this. In addition, the delivery of the mirrors is expected to be before the end of 2019. This leave 12 months or less to find a solution or at least to select the coating and protective layer of the mirrors in the PBIP.

References

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[2] Cheol Woo Lee, Young-ouk Lee, and Young-sik Cho. Estimation of the Production of Ozone and Nitric Acid in a Proton Accelerator Facility of the Proton Engineering Frontier Project. 8(2):10–11, 2007.

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[1] Kugler: `https://www.kugler-precision.com`