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Luminescent Coating R&D Status and Plans

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Abstract

This document presents the status of the luminescent coating project for the Target Imaging Systems. The project has not reached yet the maturity expected at the CDR level. This is mainly due to external event delaying the qualification of the coatings, and technical choices lately selected for the manufacturing of the target wheel and proton beam window. The state of knowledge developed is however sufficient to decide which coating material has to be selected for the first target wheel and proton beam window. In anticipation to the evolution of the project, new contract has been placed to permit the possibility to coat the target wheel in situ and at more suitable time, putting the coating of the target wheel out of the critical path. The delivery of the industrial coating process, which has been initially developed on a plasma gun is now been completed with well established portable combustion gun technique. The changes in execution of the project plan are presented through the delivery of the industrial process. In addition, plan for the necessary research and development for the future coating material is detailed. In summary, this updated coating development plan supports the project schedule for Accelerator and Target

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1 Introduction

At the PDR, it has been exposed that there are no existing luminescent coating materials that can satisfy all the requirements. Namely, a coating luminescent material for the ESS target imaging system shall:

1. yield sufficient number of photons per proton in order to permit the imaging system to produce an image per pulse and reliable information on the proton beam on target properties
2. emit a spectrum different from environmental gas luminescent spectrum
3. maintain luminescent properties at the target temperature
4. be radiation tolerant, maintaining luminescent properties during the lifetime of the Target Wheel / Proton Beam Window
5. have a lifetime short compared to target wheel motion

The only candidate is so far the chromium alumina powder provided by a unique vendor, Brodmann, running a small business and located in the U.S.A. This material, in use at SNS, is the only one satisfying the radiation tolerance requirement. Other chromium alumina tested at SNS have failed. This material constituted the baseline for the first ESS coatings. But, in the case of the Target Wheel (TW) imaging system, it doesn't satisfy the lifetime requirement, and barely satisfies the operation temperature requirement. For the Proton Beam Window (PBW), and perhaps for the screens of the Dump Line (DumpL), this material may satisfy the requirements.

2 Status of the Luminescent Coating Project

The coating project has many objectives:

- select and qualify the luminescent material for coating the first target wheel, proton beam window and screen for the DumpL
- deliver the industrial process for coating the selected material on the target wheel, proton beam window and screen for the DumpL
- understand the properties of the luminescent coating material under which the material satisfies the stated above requirements
- study and qualify new materials which has identical or better performance than the Brodmann powder

The first two items above, as discussed in the document ESS-0150759, constitute the immediate objective of the project. For the imaging systems in the target and DumPL areas to operate at all, a luminescent material has to be coated on the TW, PBW and screens for the DumpL. And to permit the coating process on high value equipment such as the TW or the PBW, an industrial process assuring the necessary quality assurance has to be established.

The last two items are longer term project. The dependence in a unique supplier for the coating material is critical. Therefore, a sound understanding of the properties that makes not only the material luminescent fast decayed at high temperature, but also radiation tolerant for the defined TW lifetime, is the first and fundamental step towards the engineering and production of a new coating material for high power targets.

2.1 Coatings for the first TW, PBW and DumpL

The first elements for the ESS Imaging Systems will be coated with the Brodmann powder. Indeed, the first studies and qualification process undertaken so far were done on the new unqualified Brodmann chromium alumina formula (see ESS-0150759).

Sample production: to start with, the collaboration with University West led to significant results, demonstrating the new powder to be luminescent after been coated with their axial plasma spray gun. Doing so, a different coating technique has been developed, establishing which parameters successfully make the powder luminescent. A series of samples have been produced by University West, and the series of tests to study and qualify the samples have been started. Luminescent properties have been measured at Oslo University and at ESS:

- photo-luminescence yield: `https://confluence.esss.lu.se/display/BIG/SNS+Photo-Luminescent+Yield`
- luminescence lifetime decay: `https://confluence.esss.lu.se/display/BIG/Characterisation+of+the+HV+samples`
- luminescent relative yield vs. temperature: `https://confluence.esss.lu.se/pages/viewpage.action?pageId=61211954` and
- iono-luminescence (from protons): `https://confluence.esss.lu.se/display/BIG/Proton+luminescence+characterisation`

XRD: X-Ray Diffraction measurements of all produced samples have been carried out at University of Oslo, in order to understand the structure related to the luminescence. They showed the most luminescent material to be the one with high content of alpha-phase, and thus confirm the coating process. The documentation is in `https://confluence.esss.lu.se/display/BIG/Characterisation+of+the+HV+samples`

Irradiation tests: the qualification tests for radiation tolerance have been started, with irradiation of 7 of the different samples produced at the BLIP facility. The post-irradiation examination (PIE) has not been carried out yet, and suffer a delay of 1 year. Indeed, the samples where in a cassette together with tensile samples. The planned irradiation dose should have been reached with 8 weeks of irradiation. Unfortunately, the Linac delivering the irradiating beam failed, leaving the samples with only 5 weeks of irradiation. The remaining 3 weeks, required for the tensile samples, will be achieved after January 2018. Hence, the PIE, involving XRD, SEM, and other material and luminescence characterization techniques will eventually be carried out after the radiation cooling period which brings the material in the sub mSv radiation range, and which corresponds to 4 months minimum after the end of the irradiation.

New irradiaton campaign: in order to mitigate this delay, collaboration has started with the Danish Technical University (DTU), where irradiation of 4 of the same plasma coated samples have been agreed. The irradiation took 3 months of preparation and will start on the 26th October. The objectives of the irradiation campaign at DTU is not only to qualify the samples, but also to be able to study the material during the irradiation, using its luminescence properties. In addition, PIE on these samples is planned at various institutes, where XRD and XAF or similar X-ray spectroscopy techniques can be used, to characterize the structural degradation and its relation to the luminescence properties, as function of the irradiation dose.

Combustion Coatings As explained in ESS-0150759, ESS contracted University West to develop of a combustion gun, similar to the one in Stony Brook which is used for the SNS target coatings. The objective is to provide an in-situ coating, in order to respond to the quasi impossible usage of the axial plasma gun on the TW. The initial agreement with ESS and in-kind partners to manufacture the TW Beam Entrance Window (BEW) in 6 pieces to permit plasma coating cannot hold. It has been found that welding the BEW is a week point in the TW and thus carries a high risk for the project.

The first combustion gun project is now operating: University West has bought a gun for ESS and developed their first successful chromium alumina coatings using the gun and Brodmann powder. The same characterisation as for the plasma coated samples will follow, in the next 12 month, following the qualification and the industrial coating process.

Discussion and agreement with ESS Target Division showed the industrial process delivery will need significant input from ESS target division and in-kind partners in charge of delivery of the TW and PBW, namely, defining the requirements to maintain integrity of the TW and PBW during the coating process, understand and integrate the coating in their schedule. Requirements are documented in the interface control documents ESS-0032631 and ESS-0060561.

2.2 Future Coating Materials

The chromium alumina has been a good candidate for the SNS. But it presents characteristics that do not satisfy some requirements for the ESS Target Imaging Systems. The luminescence yield degrades under radiation rapidly to 1% level of the initial yield. The temperature dependency is strong, decreasing by more than a factor 2 at 200 C°. Moreover, the luminescence lifetime is slow compare to the ESS pulse, therefore, no fast detection within a pulse can be done. The research carried on at ESS and with collaborators (Oslo, HV, SNS, J-parc) on new candidate luminescent materials for coating on high power target is essential for the future ESS targets, starting from the second coated PBW or TW, whichever comes first. The objective are to deliver a better performing luminescent material and to control the its manufacturing. Indeed, the unique material provider which is Brodmann is a high risk to the project and can cause serious delays. The research started and driven by the ESS team aims at finding and engineering luminescent materials for high power targets which can be provided by several chemical industrial companies.

A family of luminescent materials based on Yttrium is been investigated. Several material have started to be produced at ESS and at University West.

Yttrium oxide has been prepared at ESS as a luminescent material. It has been successfully coated, using the plasma gun by University West, and characterised at ESS and at Oslo University. A sample has been irradiated at BLIP. It is thought to be a good candidate material. According to literature, it has a lifetime in the 10s of ns range; it is used as a high temperature luminescent material, although the ceramic yttrium oxide studied at Oslo showed a similar temperature dependency to the chromium alumina, and a smaller yield; it is not doped, so, probably more radiation tolerant than the chromium alumina. However, this is all prospective at the moment, and only the complete characterisation can tell whether yttrium oxide is a qualified luminescent coating for high power targets.

Yttrium tungstate has been prepared in the ESS lab. Attempt to coat this material has not been successful yet. However, this material is more promising than yttrium oxide. It is equally fast, with less than μs lifetime (limitation of the measurement test bench). It is also a luminescent material used at high temperature in industry; it can be doped to enhance specific narrow spectral bands; it has the potential of been reduced under irradiation, with the apparition of additional fast and strong sharp lines generated by the radiation dose. This phenomena observed at SNS on the chromium alumina (`https://confluence.esss.lu.se/display/BIG/Preparation+for+measurement+of+the+O%3A777.5nm+line+at+SNS`) is expected to be seen with this material, with a high probability; initial photo-luminescence characterisation with a series of powder doped with lanthanides (`https://confluence.esss.lu.se/display/BIG/Characterisation+of+the+Y2WO6+doped+samples`), and showing a strong luminescence.

chromium alumina the new formula form the Brodmann powder has not been fully qualified for the ESS target. This remains to be done. In addition, understanding its radiation tolerance is critical; qualifying another powder which can be prepared in-house is equally critical.

3 Concluding Remarks and Planning

Significant progress have been realised in characterisation and qualification of the first coated luminescent material. The Brodmann chromium alumina material has been selected, and the industrial process is under control. Complete characterisation remains to be done. Luminescence properties will be done at ESS and at Oslo, and the radiation tolerance qualification is planned to be done at DTU.

The industrial process for coating the TW and PBW will be finalised, with the specification of the requirements that are missing. The clarification of the inclusion of the coating in the schedule and manufacturing of the TW and the PBW has been discussed with Target division, and is documented.

Planning for the research activity is established, to select, based on educated choice, at least one luminescent material that can satisfy all ESS target imaging system requirements, and by extension most of the modern high power targets imaging systems requirement.