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CHARACTERIZATION OF NEG COATINGS FOR SLS 2.0

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Abstract

To limit desorption and ameliorate pumping of the narrow 20 mm aperture vacuum chamber of SLS 2.0, it is planned to fully coat it with Non Evaporable Getter (NEG) material. NEG coating can be produced with different structural characteristics, from dense films to columnar growth, with corresponding distinct electrical properties affecting the machine impedance and the instability threshold of the accelerator. In order to evaluate and characterize the coating process for geometries similar to the chamber at SLS 2.0, we measured the resonance properties of coated and uncoated shorted waveguide pieces. First tests were done with standard X band waveguides at 12 GHz. Test setups using race track cross sections are in preparation, also at 12 GHz. To characterize super thin NEG layers a quasi-optical test stand has been developed, which allows to measure surface impedances at 100 GHz. The final goal is to have a standardized process to test samples coated by external producers. We describe the setups and first results.

INTRODUCTION

After 18 years of user operation, an upgrade of the Swiss Light Source (SLS) is planned for the period 2023/24 [1]. The new design optics with a design emittance lowered by a factor of 40-50 employs a state of the art multi bend achromat optics made possible by small aperture magnets and, a special feature of SLS 2.0, longitudinal gradient magnets [1, 2].

The magnet design requires a small aperture (17-20 mm) beam pipe, which leads to two interrelated challenges. The first is that vacuum conductance in the chamber is quite low. Taking into account normal desorption behavior, an excessive amount of beam conditioning is required to arrive at pressures below 10^{-9} mbar. Coating the chamber surfaces with Ti-Zr-V Non Evaporable Getter material simultaneously gives distributed pumping and reduces radiation induced gas desorption from the chamber walls. In this case, beam doses of 100 Ah are sufficient for conditioning [1, 3].

The second challenge is the significantly increased contribution of resistive wall effects to the machine impedance, it grows with the inverse square of the chamber diameter. A part of that can be compensated by using copper or copper coated chambers. But this is mitigated by the electric properties of NEG. Depending on the material structure, columnar or dense [4], a conductivity between $\kappa = 1.4 \cdot 10^4$ and $8 \cdot 10^6$ S/m can be expected [5] – for comparison, the value for copper is $5.8 \cdot 10^7$ S/m. Due to the skin effect, the surface impedance will be influenced by the properties of both NEG and copper, with NEG starting to dominate for higher frequencies. Longitudinal single bunch instabilities as the microwave instabilities happen at wavelengths smaller than the bunch length and corresponding high frequencies. The influence of NEG should be still small in that region, so that we are looking for extremely thin coatings of 500 nm down to 200 nm thickness.

The surface impedance plays a critical role on the machine stability of SLS 2.0. Depending on thickness and conductivity, the stability thresholds can become dangerously low. So we decided to start a measurement program to do an RF based characterization of coatings. General RF characterization of NEG properties were already done at 7.8 GHz in [5] and 220-330/500-750 GHz in [6], so our interest lies in making sure, that we have the right type of NEG, to measure thin coatings, but also to evaluate production processes in analyzing samples. The general approach is to measure coated and uncoated resonators with respect to their internal losses and so obtain the surface impedance.

An interesting question is the relation between measurement frequency, coating thickness and conductivity. As can be seen in the two upper graphs of Fig. 1, a direct measurement of the conductivity should ideally use thick coatings above 1 µm in combination of high frequencies beyond X band. A measurement of the thickness, as shown for dense NEG in the third graph, is possible at X band frequencies for value beyond 1-2 µm. Super thin layers require higher frequencies of, e.g., 100 GHz.

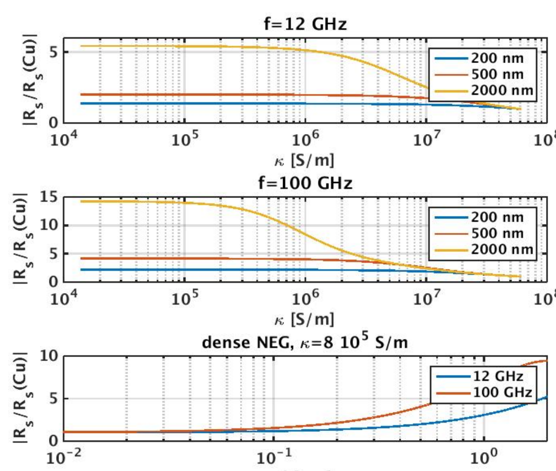

Figure 1: Analytically calculated surface impedance of thin NEG coatings on copper substrate normalized to uncoated copper: variation with conductivity and coating thickness.

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We are, however, running into a conflict here. For ease of measurement, we would like frequencies near the fundamental mode to avoid spurious mode coupling effects, which restricts us for the standard 20 mm chamber of SLS 2.0 (cut off around 8 GHz) to frequencies in the X band regime. Super thin coatings below 500 nm will be not detectable, so that a different high frequency setup is required.

Following that, our measurement strategy is the following. We will be using X band setups with waveguide sections, race track and round tubes to test thick coatings to check the technology on chamber like geometries. To characterize super thin coatings, probes in the shape of planar mirrors will be prepared, which can be tested in the quasi-optical Fabry-Perot resonator at 100 GHz. In the following, we describe both approaches and give first results.

THICK COATINGS: MEASUREMENT AT 12 GHz

The ideal test geometry in terms of similarity to the SLS 2.0 vacuum chamber would be a round tube. But in this geometry, we have two degenerate modes, the TE_{11} dipoles in horizontal and vertical polarization. Any asymmetry, due to coupling or due to deformations of the tube, leads to cross coupling between these modes. We cannot be sure about the field (and loss) distribution over the chamber wall. A clean relationship between the quality factor of the resonance and the surface impedance is lost.

This is the reason, we work with non circular cross sections. For a first test, we decided to use a 1.3 meter long section of WR90 waveguide. Two pieces were measured, one the original copper waveguide and the other NEG coated one. The transverse distribution of the coating thickness depends on the distance between the coating wire and the surface. To improve the homogeneity, two parallel wires were used during the sputtering. Figure 2 shows the cross section of the WR90 waveguide together with the theoretical thickness distribution as simulated with a custom Monte Carlo code written by one of the co-authors (H.P. Marques). In a first run, only part of the waveguide was coated, so that a second iteration was added. As a result, the first 20 cm is coated with an average thickness of 3.1 µm and the remaining length of 110 cm of 5.1 µm. Combining the analytical field distribution of the TE_{10} with the thickness data shown in Fig. 2, the power loss in the waveguide can be calculated.

Figure 3 shows the measurement setup. The waveguide – the device under test – was electrically shorted on both ends to create the resonator. Coupling in and out was done with a 30 dB directional coupler of the double loop type. The most practical way to do the measurement was to measure the transmission through the resonator.

The components of the setup, the shorts and the directional coupler, were characterized separately with a network analyzer. The data was combined with the theoretical model of the coated/uncoated waveguide to predict quality factors for different surface impedances. These are equivalent to insertion loss, from which we can derive the conductivity.

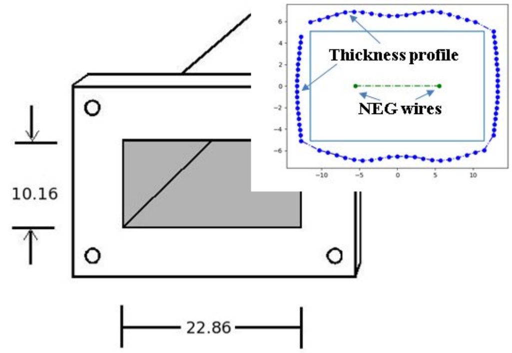

Figure 2: WR90 waveguide geometry showing location of NEG sputtering wires and resulting theoretical thickness profiles.

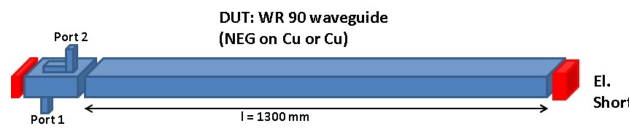

Figure 3: 12 GHz measurement setup.

As shown in Fig. 4, we were clearly able to identify copper coatings and NEG coatings. It is also quite clear, that the coating process created dense type NEG – a columnar type of NEG would have resulted in a significantly different result.

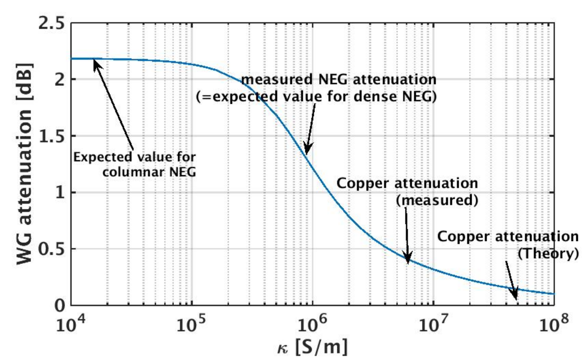

Figure 4: Calculated attenuation and conductivity together with known data points.

An interesting feature of this type of measurement is also, that we don't rely on a comparison with known materials (e.g. copper) to measure the surface conductivity, but we do a direct measurement. Currently, we are in the process of preparing tubes with a race track cross section with the thinner average NEG thickness of 2 µm. We hope, that this type of structure can be used as test piece to validate the coating process.

THIN COATINGS: SETUP FOR 100 GHz

To be able to see ultra thin coatings of 500 nm and below, we have to get up in frequency into regions of 100 GHz. Waveguide structures and tubes at these frequencies have

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tiny apertures, which become impossible to coat with the classical magnetron sputtering process.

At these frequencies, quasi-optical resonator structures in the form of Fabry Perots have been successfully used to measure lossy surfaces [7, 8]. Figure 5 shows the setup, as we are planning to use it. It consists of the symmetric half of a classic Fabry Perot, where the large mirror, fabricated from copper, connects to a pair of mutually tilted WR10 waveguide to coupling in and out to the resonance.

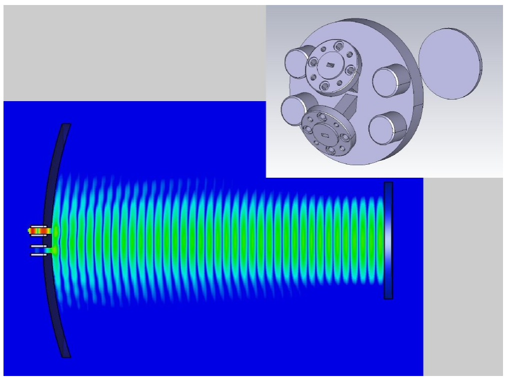

Figure 5: Field distribution of Fabry Perot including 3D structure.

In the waist of the Gaussian beam sits a planar probe mirror, which is our NEG coated sample. With a diameter of 24 mm, it should be small enough to introduce as a sample plate into the coating facility. As can be seen in Fig. 6, we have a pronounced effect of the losses on the sample surface on the sharpness of the resonance. Table 1 gives the specification of the Fabry-Perot and shows relation between sample conductivity and the quality factor of the 100 GHz resonance.

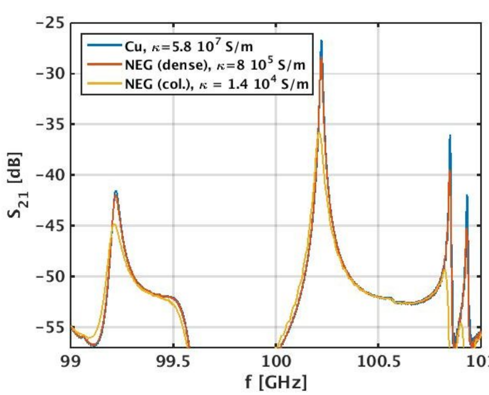

Figure 6: Calculated transmission between waveguides, the $TEM_{0,0,38}$ resonance sits at 100.2 GHz.

OUTLOOK

The main interest in this program is not to measure the fundamental properties of Non Evaporable Getter materials by itself, but to characterize test pieces and samples in terms of the kind of material (dense versus columnar NEG) and the thickness distribution with respect to their application for SLS 2.0.

Table 1: Specification of Fabry Perot Setup. With a slightly larger mirror diameter, the separation can be enlarged leading to a higher sensitivity. Q factors were computed from the S_{21} values shown in Fig. 6.

Technical specifications	
mirror separation	60 mm
curvature spherical mirror	83.7 mm
Ø spherical mirror	48 mm
Ø planar probe	24 mm
coupling	WR10 tilted at 30^o
Loaded Q (spherical mirror in Cu)	
Copper probe ($\kappa = 5.8 \cdot 10^7$ S/m)	8489
dense NEG ($\kappa = 8 \cdot 10^5$ S/m)	6967
column. NEG ($\kappa = 1.4 \cdot 10^4$ S/m)	2657

Using sections of WR90 waveguide, we saw, that the most sensitive approach was to measure standing wave resonances in the guide. Inhomogeneities in the coating due the rectangular cross section were successfully taken into account and we were able to clearly identify the type of NEG used. The next step, planned for the second half of 2019, will be to use thinner 2 µm coatings with a race track like cross section more similar to the circular one of SLS 2.0 and we will explore, whether we can define a kind of standardized test piece.

Two microns are still rather thick compared to the design values in SLS 2.0 of 200-500 nm, so a second test stand working in the quasi-optical domain at 100 GHz is in development, which can be used to characterize small planar samples. The electrical design is finished and we are in the process of looking at mechanical design. If everything turns out as expected, we would expect first measurement towards the end of the year.

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