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PROGRESS OF MgB_2 DEPOSITION TECHNIQUE FOR SRF CAVITIES AT LANL

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Abstract

Since its discovery in 2001, Magnesium Diboride (MgB_2) has had the potential to become a material for cavity manufacturing. Having a transition temperature (Tc) at ~39 K, there is a potential to operate the cavity at ~20 K with cryocoolers. This will open up a variety of applications that benefit from compact high-efficiency superconducting accelerators. We have found a 2-step deposition technique as a viable technique for cavity coating, i.e., coating of a pure boron layer with chemical vapor deposition using a diborane gas in the first step and react it with Mg vapor in the second step. In this paper, we will show some recent results with up to Tc ~38 K using a small furnace and describe a new coating system under construction with a new 3-zone furnace to coat a 1.3-GHz single-cell cavity.

INTRODUCTION

Niobium superconducting radio frequency (SRF) cavities have been used in particle accelerators for a long time and thanks to research and technological effort they are now approaching their theoretical gradient limit of 50 MV/m [1, 2]. The raw material cost has also quadrupled over the last 20 years, leading to a substantial increase in costs for new SRF particle accelerators. Another large cost for an SRF particle accelerator comes from the cryoplant, necessary to cool down Nb cavities at ~2 K by immersing the cavity in superfluid helium. To address these issues alternative materials with a higher transition temperature (T_c), such as Nb_3Sn [3, 4], are being explored: operating at a higher temperature would remove the need of superfluid helium, simplifying the cryoplant and driving down cost.

Another material of interest is magnesium diboride, MgB_2: discovered in 2001 [5], it exhibits superconductivity below ~39 K, four times the T_c of niobium and twice the T_c of Nb_3Sn. If cooled to 20 K the theoretical highest acceleration field that a MgB_2 cavity would produce is approximately 50 MV/m for a typical electron accelerator, comparable to Nb at 2 K. These properties make MgB_2 a very attractive material for SRF cavities, since operating a facility at 10 times today's temperatures could lead to replacing liquid helium cooling with closed-circuit cryocoolers.

As of the writing of this paper, very few MgB_2 full SRF cavities have been manufactured [6]. This could be due to the fact that one of the reagents (B_2H_6) required to obtain a boron film is toxic, which may discourage its use. The current research approach is to deposit MgB_2 via a co-deposition process [7] where a substrate is exposed to carefully controlled B_2H_6 gas and Mg vapour quantities, leading to the deposition of the superconductor. While this approach has proven successful on flat samples it is still not perfected to deposit on 3D surfaces, like a cavity.

In this paper we present the more recent results of the two-step deposition technique developed at LANL, with T_c and chemical composition results. We will also describe briefly a new MgB_2 coating facility for 1.3-GHz cavities under construction and scheduled to be completed by the end of September 2021.

EXPERIMENTAL SETUP

We restarted our experiments to react B films with Mg vapor. Some details of the experiment are written in [8]. The B films used for these experiments were prepared by flowing B_2H_6 gas through a 1.3-GHz cavity in the previous project that ended in 2015. Figure 1 shows the locations of the samples we used for these experiments.

The B and Mg reaction procedure is similar to the work of Hanna [9].

Since the new deposition facility that will be used to coat a full-size cavity won't easily allow a fast cooling step like the small tubular furnace in Fig. 2 tests were performed with a slow cooling step after the Mg evaporation. Since the highest value of T_c was obtained by depositing Mg at 700 °C this was the temperature chosen for the Mg reaction.

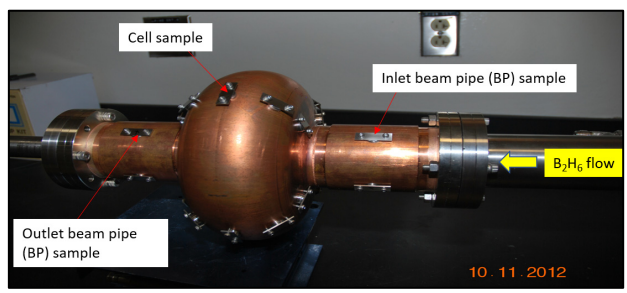

Figure 1: The location of B samples that were taken from the previous project that ended in 2015.

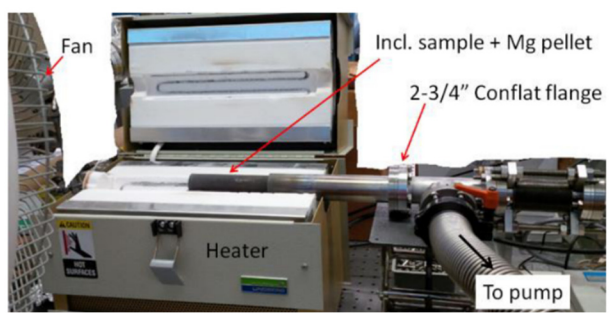

Figure 2: Experimental setup.

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Two samples were selected, one positioned at the outlet of the cavity during the deposition and one at the cell equator. The reaction was performed as previously described but, instead of opening the furnace and forcefully cooling the reaction chamber at the end of the deposition, the furnace was turned off and let cool naturally.

Figure 3 shows the temperature evolution over the duration of the reaction.

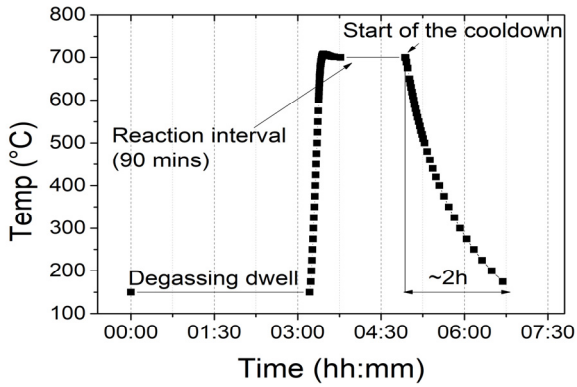

Figure 3: Temperature evolution of slow cooling reaction.

Compared to the fast cooling step, the time required for the reaction chamber to reach room temperature went from 10 minutes to 3 hours (2 hours to 150 °C).

Table 1 shows the T_c measured with a SQUID magnetometer for the samples obtained by slow cooling and fast cooling after the deposition. Both the inlet/ outlet and cell samples show a very similar T_c, indicating that the cooling time does not seem to affect the superconductivity properties, at least for what concerns the critical temperature.

Table 1: T_c of Samples Obtained at Different Cooling Steps

Position	Slow cooling T_c	Fast cooling T_c
Cell	35.6 K	35.3 K
Outlet	37.9 K	—
Inlet	—	38.0 K

The chemical composition of the samples was studied and the XPS results are shown in Figure 4 and Figure 5. For the sample that shows a higher T_c (Outlet, 37.9 K) shown in Fig. 3 the ratio of Mg:B is close to being 1:2, with Mg at a concentration between 25% and 30% and B between 50% and 60%. There still is oxygen present in the film at a concentration of 30% at the surface then decreasing to 20% deeper in the film. This could explain the T_c being lower than the nominal value. The reason for high oxygen level could be due to the fact that the B films used had been stored in poor vacuum for more than 5 years.

For the sample grown on the cavity cell in Figure 5 instead the Mg:B ratio is far from being the stoichiometric 1:2, starting from a 1:1.5 (20% Mg, 30% B) on the sample surface to a 1:2.4 (25% Mg, 60% B) deeper into the film. Oxygen is also present with a concentration of 30% at the surface, dropping to 15% deeper into the film. Both the ratio of Mg:B not being optimal and the oxygen presence could be the reason for the drop in T_c seen in the sample, although to understand the contribution of each factor more studies are needed.

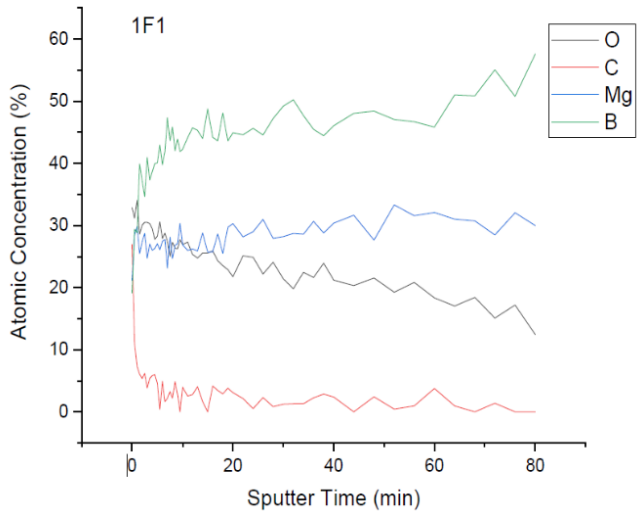

Figure 4: XPS of outlet sample obtained at 700 °C and slow cooled.

It is worth to mention that both samples exhibit a quantity of oxygen throughout the film that is higher than expected for films that achieve a high T_c.

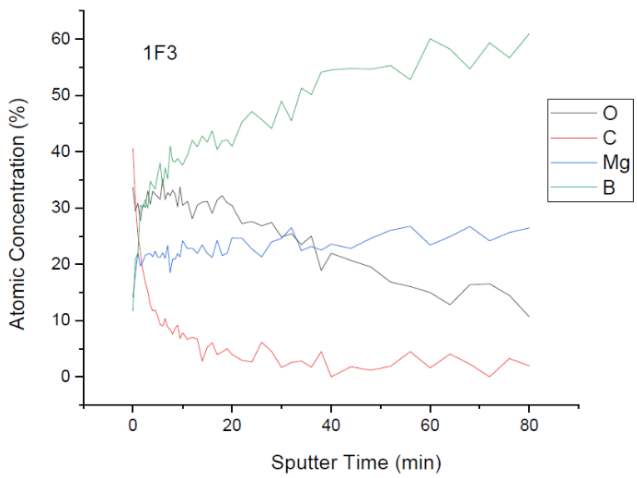

Figure 5: XPS of cell sample obtained at 700 °C and slow cooled.

NEW COATING SYSTEM

Figure 6 shows a 3D model of the new deposition facility being developed at LANL for the study of MgB2 coatings. The main heater (3-section furnace) is capable of heating three separate areas to 1100 °C, although for the deposition of MgB_2 we are not planning to go above 750 °C.

For safety reasons the exhausted process gases will flow through an additional heater – shown in figure – that will decompose any residual B_2H_6 to a nontoxic compound. As of June 2021 we're waiting to receive the furnaces, the last component that we'll need to proceed with the first tests.

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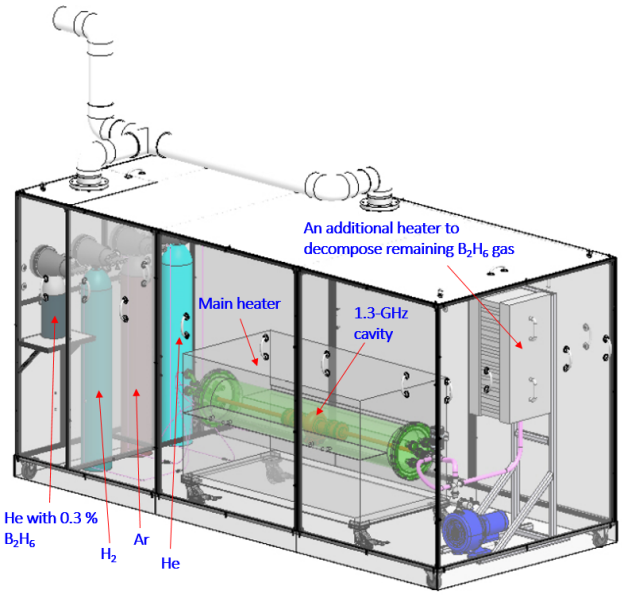

Figure 6: New coating system model.

CONCLUSION

A slow cooling procedure was tested to better mirror the real deposition conditions of a large furnace where fast cooling would be difficult to implement. Compared to our previous results, the cool down temperature doesn't seem to affect the material properties, but further studies are needed to affirm these results.

We were able to secure funding to purchase the large 3-zone tubular furnace and other components to construct a new MgB_2 coating system, in order to progress the studies on the coating process and to eventually perform a complete coating procedure of a 1.3-GHz RF cavity. We plan to coat MgB_2 on a cavity that will be provided by KEK and test it at KEK by summer next year. LANL will also have a capability to perform low-power tests using a cryocooler. If successful, MgB_2 coated cavities could be a new addition to a new category of SRF cavities that can be run using compact cryocoolers and could open up new applications. It could also help raise the achievable accelerating gradient with a thin or multilayer coating of MgB_2 films on Nb cavities.

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