Development of MgB_2 Coated Superconducting Cavities

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Introduction

Niobium superconducting cavities are the baseline accelerating structure for the International Linear Collider (ILC) with a design accelerating gradient E_{acc} of 31.5 MV/m. The theoretical limit of E_{acc} is derived from superheating surface magnetic field (B_{sh}) and Table 1 shows the expected B_{sh} and corresponding maximum E_{acc} of Nb, Nb_3Sn and MgB_2 for the cavities with B_{peak}/E_{acc} = 4 mT/(MV/m), a typical number for electron accelerators. As one can see, Nb_3Sn and MgB_2 have a potential to raise the achievable accelerating gradient significantly in the future. This table includes the number at 20 K for MgB_2 since the transition temperature for MgB_2 is ~39 K and it can possibly be operated at 20-25 K with cryocoolers. Nb_3Sn has been studied for decades and the techniques to get a high-quality film on the interior cavity surface have made excellent advances in recent years [1]. Regarding MgB_2, it was discovered to be superconductive in 2001 and its RF properties have been studied using small flat samples with favorable results [2]. Also, some attempts to coat small cavities up to 3 GHz have been made in the last few years. We propose to investigate the development of techniques to coat MgB_2 on cavities for the future HEP accelerators. They represent an important approach to improve the efficiency and cost of operation of next generation SRF cavities.

Table 1: Thermodynamic critical field (B_c), superheating field (B_{sh}) and corresponding accelerating gradient for Nb, Nb_3Sn and MgB_2. The ratio B_{sh}/B_c is from the theory in [3] except for Nb.

Material	B_c [mT]	B_{sh}/B_c	B_{sh} [mT]	Corresponding Accelerating Gradient*1 [MV/m]
Nb at 2 K	191	1.2	229	57
Nb_3Sn at 2 K	529	0.842	445	111
Nb_3Sn at 4 K	509	0.828	421	105
Nb_3Sn at 10 K	373	0.784	292	73
MgB_2 at 2 K	433	0.845	366	92
MgB_2 at 4 K	429	0.842	361	90
MgB_2 at 10 K	405	0.823	333	83
MgB_2 at 20 K	320	0.789	252	63

*1Assuming 4 mT/(MV/m), which is typical for an electron accelerator.

Current situation on the MgB_2 coating development

In the last few years, Temple University has been a major player in terms of the effort to develop the technique to coat MgB_2 on the cavity interior surfaces [4 - 6]. They have been developing a technique based on the hybrid physical chemical vapor deposition (HPCVD) that has been well known to produce a high-quality film. They have developed a system to coat a 3 GHz single-cell cavity and started to coat a cavity recently. ANL has been working on a technique using atomic layer deposition (ALD), which is known to be one of the best techniques for conformal coating of complicated 3D structures [7]. LANL has been developing a 2-step technique, e.g., coating of B layer with CVD in the first step and react it with Mg vapor in the second step [2, 8]. Unfortunately, all these efforts have been very slow due to insufficient funding.

Goals in the next 5 and 10 years

The above mentioned 3 techniques should move forward for the following reasons. 1) HPCVD has been known to give a high-quality film and most advanced so far, 2) ALD will be more appropriate to coat complicated structures such as a normal-conducting copper high-gradient structure and low-β cavities, and 3) 2-step technique may be better than HPCVD for a simple elliptical cavity once the technique is optimized due to its simplicity leading to better uniformity and reliability.

The goals in the next 5 years include 1) parameter optimization for each technique, 2) coating of 1.3 GHz Nb or Cu single-cell cavity and test them, and 3) identify issues, address them and demonstrate the benefits of MgB_2 cavity.

Assuming these goals are accomplished in the first 5 years, the goals in the following 5 years will be 1) design and develop a coating system for a multi-cell cavity such as the ILC 9-cell cavity, 2) carry out parameter optimizations for high-quality uniform coating using coupons attached to each cell, 3) coat multi-cell cavities and test them, 4) identify issues and address them, and 5) produce MgB_2 coated cavities that are superior to Nb cavities and possibly to Nb_3Sn cavities.

Additionally, exploring the idea of coating films that are thinner than its penetration depth to raise the achievable surface magnetic field due to the fact that B_{sh} rises in such a film [9 - 11] should be pursued as well.

References

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