ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI112

BASIC RESEARCH ON RF ABSORBING CERAMICS FOR BEAM LINE HOM ABSORBERS*

R.Eichhorn#, V. Shemlin, P. Quigley, CLASSE, Cornell University, Ithaca, NY 14853, USA
A. Rae, J. Matteson, NanoMaterials Innovation Center LLC, Painted Post, NY, 14870, USA
W. Carty, Alfred University, Saxon Dr, Alfred, NY 14802, USA

Abstract

Higher Order Mode (HOM) absorbers for future high current machines have been a challenging component for many years. Even though many different materials are commercially, none of them seems to fully qualify for accelerator applications. Some of them are brittle or chippy, others porous, have small bandwidth of absorption, a high dc resistivity leading to charge-up or are unreliable in terms of batch to batch variations. Alfred University and Cornell University have recently partnered in developing a dedicated absorber ceramic material that tries to overcome these limitations. We will report on results from small samples of different compositions we produced based on SiC, graphene and graphite.

INTRODUCTION

The potential for excellent quality of X-ray beams, generated by a low-emittance electron beam, motivated the design of a 5-GeV superconducting energy-recovery linac (ERL) [1,2] at Cornell University. Due to the high beam current combined with the short bunch operation, a careful control and efficient damping of the higher-order modes (HOMs) is essential. HOMs excite the beam and lead to instabilities and particle losses. HOM dampers absorb this RF power and are a critical component. In high current storage rings with superconducting cavities (like CESR @ Cornell) strong broadband HOM damping has been achieved by using beam-pipe ferrite loads operating at room temperature [3].

While HOM dampers have been used in accelerator physics for several decades, modern accelerator design favor short particle bunches, which potentially excite HOMs up to 40 GHz and above. In addition, compact layouts require the absorption at cryogenic temperatures.

Both frontiers, the high frequency and the low temperature regime, have so far not been addressed successfully.

MOTIVATION

There are several problems with HOM dampers: obtaining the desired electromagnetic absorption properties across the HOM frequency band; maintaining mechanical integrity of the HOM damper structure across a large thermal gradient (cryogenic to room temperature); high-vacuum compatibility (low degas rate); and achieving a finite electrical conductivity at low temperature to dissipate static charge.

*Work supported by the DOE under DE-FOA-0000760
#r.eichhorn@cornell.edu

SiC based HOM damper materials, or absorbers, have been designed and tested [4,5,6] but fail in one or more of the listed areas. One reason is the lack of reproducibility in the SiC material, such as may be due to a deleterious grain size distribution and lack of homogeneity. An additional factor is the unwillingness of ceramic manufacturers to develop a custom product for this application. This triggered the R&D on basic ceramic research, conducted within an DOE SBIR phase I grant. The underlying idea was to have a good conductor (like graphene) interlaid in the lossy material matrix, as indicated in Fig. 1.

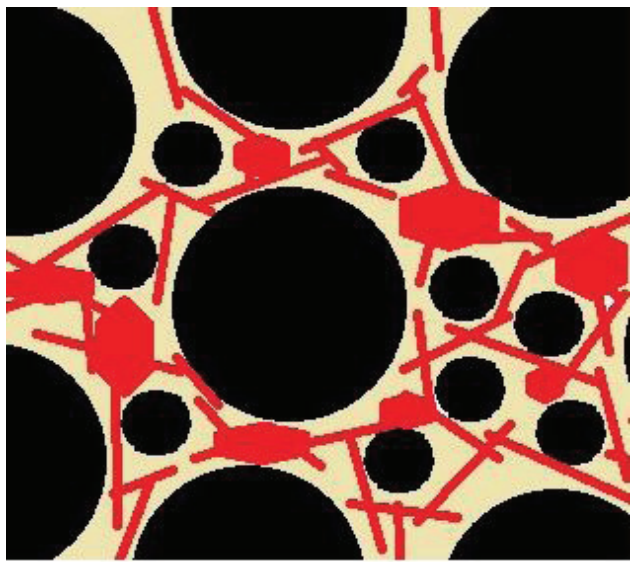

Figure 1: Desired microstructure (schematic) black represents the bulk material, yellow the grain-boundary glassy / crystalline phase and red the graphene flakes.

MATERIAL SELECTION

Our plan was to develop a ceramic composite. The constituents were initially combined in the form of powders. The powder particles are bonded and the composite densified by means of sintering in a high temperature thermal process. After synthesis, the goal was to have the individual matrix and filler materials on a micro-scale be distinct and unreacted, but in combined bulk form to behave as a composite material with the desired HOM absorber properties. The matrix is to provide the thermal and mechanical properties, and the filler material establishes the electrical and magnetic properties. In whole or aggregate, the composite material will behave as a new and unique lossy material.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI112

We have preselected several candidate matrix materials for the composites, based on their thermal conductivity to ensure adequate heat transfer and avoid overheating of the ceramics. In this project used silicon carbide (SiC) and aluminum nitride (AlN). These are two of the highest thermal conductivity sinterable ceramic materials available with known processability. The other candidates, beryllium oxide and boron nitride, were eliminated due to toxicity and structural integrity concerns respectively.

PROCESS DEVELOPMENT

To produce the composite material, it is first necessary to mix the matrix and filler powders, in addition to a sintering aid, into a homogeneous mixture. After mixing, the material is then cold-pressed into a prescribed geometry, pre-heated, and finally sintered within a controlled atmosphere furnace according to a thermal profile. The specific thermal profile (alternately described as a recipe or time-at-temperature) influenced the final material properties (particularly thermal and mechanical). The sintering step is crucial to final material properties.

Our original aim was to utilize a very standard methodology of solid-phase sintering of powders to generate a dense ceramic. The approach was to dry-press a coupon or pellet, vs. forming by means of a wet or slurry process (e.g., slip casting, injection molding, extruding, or tape casting). Also, the goal was to minimize machining, and the impurities generated in such post sintering methods.

Mixing was carried out by dry ball milling the ingredients. The mixed powders were dry-pressed into the requisite geometry prior to thermal processing. The pre-heating is a thermal process step utilizing both vacuum and temperature to remove free, crystalline, and chemically bound H_2O. This would be important to any of the hygroscopic materials that have absorbed or adsorbed moisture during handling, mixing, and pellet preparation. This was carried out by repeated evacuation and gas purging plus a controlled heating profile. The sintering we used processed the material via microwave sintering (2.45 GHz). Use of a vacuum chamber is preferred to remove air, moisture, and unbound water from the constituents prior to thermal processing. It was performed in either an inert atmosphere or in vacuum to mitigate the chance of oxidizing the grapheme. The thermal profile was adjusted to yield different material characteristics. Higher temperatures will result in improved particle sintering, while longer hold times will result in increased grain growth.

SINTERING RESULTS

It proved extremely difficult to obtain a dense pressed pellet even at 5% Graphene 1 (vendor 1) – some samples would not press to a green density greater than 1.5 g/cc (specific gravity of dense AlN 3.26, SiC 3.20) although graphite-containing samples densified much more predictably. We determined that the vendor 1 Graphene,

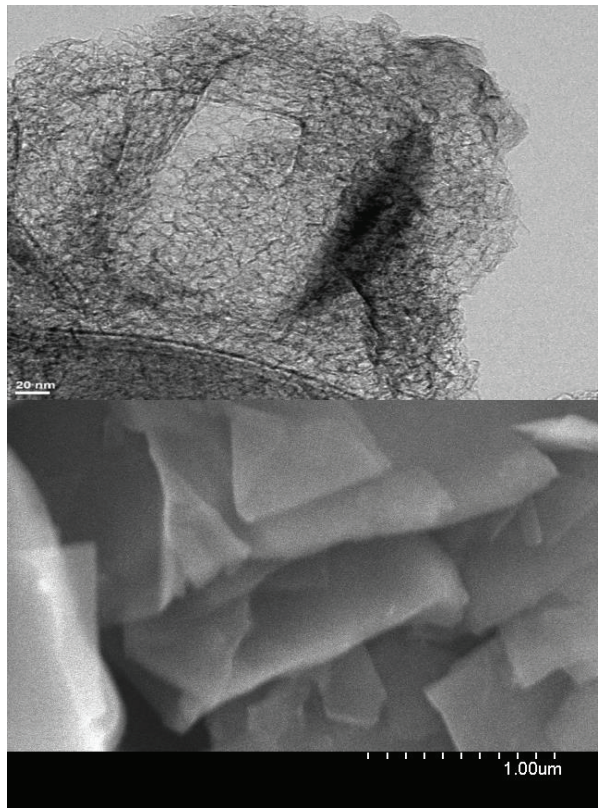

Figure 2. Graphene (vendor 1) showing hollow imprint (above), compared with Graphene (vendor 2, below) lamellar product. Magnifications are comparable.

formed by burning Mg in CO_2 had agglomerates that were much stronger than expected. Furthermore, these were in the form of "shells" that had formerly contained magnesium oxide crystals, which had been subsequently dissolved during the manufacturing process. These shells behave like springs and the pressed disks rebound considerably as pressure is released, sometimes destroying the pressed pellet. As a result, green densities were not achieved that could result in densification even though considerable liquid phase was present.

At a late stage Graphene from vendor 2 was acquired and this exhibited much better green densification presumably due to its lack of agglomerates but still exhibited weight loss and lack of densification during firing. The different behaviour and consistency of the Graphene materials are visualized in the SEMs shown in Fig. 2.

A number of configurations were used to address processing issues, a detailed description of which would exceed the objective of this paper: primarily temperature measurement, insulation issues resulting in an inability to reach target temperatures or insulation reaction with susceptors or liners, sample weight loss, lack of sample densification and surface alumina contamination – different support systems, different powder beds, the use of graphite fiber insulation and silicon carbide paper supports. Typical sample arrangements from different furnaces are show in Fig 3.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI112

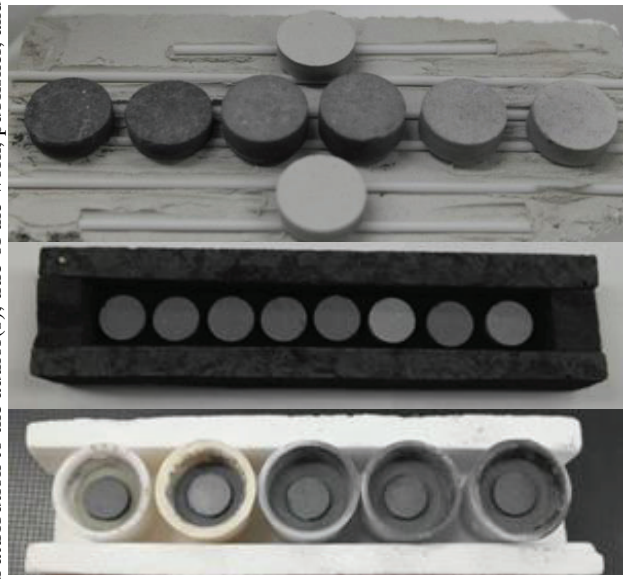

Figure 3: Sample arrangement from the tube furnace (top), Carbon-rich and nitride / carbide buried sample configurations (middle and bottom).

EM-PROPERTIES

Resistivity measurements and RF damping properties characterizations were carried out at Cornell University. In general, samples produces by conventional sintering proved to be insulating – one sample, SiC containing 6.3% carbon presented a resistivity of 83 kΩ at room temperature, measured along the sample thickness, and 605 kΩ at 77 K. The pressed and sintered samples proved too fragile for machining to microwave test configurations. Because of this difficulty we prepared the porous silicon carbide materials and started work on impregnating the pores with Graphene yielded strong machinable ceramics samples at which the microwave absorption measurements could be performed.

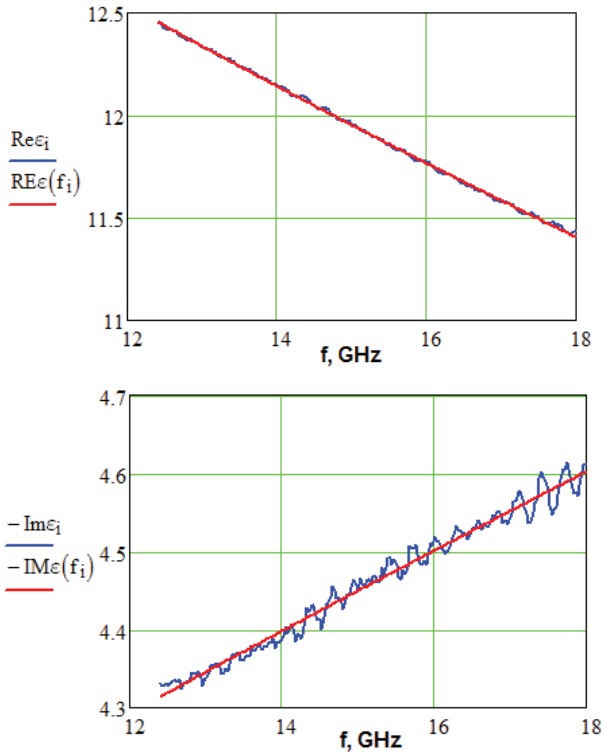

Figure 4: Microwave measurements on porous sintered silicon carbide sample impregnated with Graphene.

The complex dielectric permittivity (ε) of 4 porous sintered silicon carbide samples was measured in the frequency range 12.4to 18 GHz after machining them from a bulk material to a rectangular shape with dimensions 0.622 x 0.311 x 0.060 inches, the results are shown in Fig. 4. These samples displayed reasonable RF damping, even though the DC conductivity still was poor.

CONCLUSION

Pressureless sintering of graphene-containing compositions using conventional ceramic processing technology, even using compositions recommended by the literature, proved to be very problematic. Pressureless sintering of SiC and AlN compacts with graphene using conventional ceramic technology is impractical. We managed to obtain materials with the desired resistance range but were unable to produce materials with sufficient structural integrity to withstand precision machining to determine microwave properties.

The porous sintered silicon carbide approach developed in the second part of this study shows the greatest promise. It provides adequate mechanical strength, insulates the silicon carbide grains with a minimum number of grain boundaries and provides a route to use an infiltration mechanism that can be used to modify electrical conductivity. Microwave properties were found to be satisfactory. An analogous method might potentially be used to sinter aluminum nitride also but may be more difficult due to the relatively rapid hydrolysis of aluminum nitride powder in the presence of water.

REFERENCES

[1] Tigner, M. “A Possible Apparatus for Electron Clashing-Beam Experiments”, Nuovo Cimento, 37 -3 (1965) 1221.

[2] A M. Tigner et. al. “Cornell Energy Recovery Linac: Project Definition Design Report”, www.classe.cornell.edu/ERL/PDDR

[3] D. Moffat et al. ,” Design and Fabrication of a Ferrite-Lined HOM Load for CESR-B” Proc. of the PAC 993 (1993) 977.

[4] R. Eichhorn, et. al. ,” Cornell’s Beam Line Higher Order Mode Absorbers”, Proc. of the 2013 Int. Conf. on RF Supercond., Paris, France (2013) 1027.

[5] H. Hahn, S.A. Belomestnykh, W. Xu, “Split Higher Order Modes in Superconducting Cavities”, Proc. of the 2013 Int. Conf. on Part Acc., Shanghai, China (2013) 2495.

[6] Y. Yang, A. Nassiri, T.L. Smith, G.J. Waldschmidt, G. Wu, Y. Yang,” Mode Damping Measurement for the APS Deflecting Cavity”, Proc. of the 2013 North Am. Conf. on Part Acc., Pasaden, CA, USA (2013) 787.