The Workshop on Microwave-Absorbing Materials for Accelerators.*

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Abstract

A workshop on the physics and applications of microwave-absorbing materials in accelerators and related systems was held at CEBAF February 22-24, 1993. The gathering brought together about 150 scientists and representatives of industries from all over the world. The main topics of discussion were the properties of "absorbing" materials and how the stringent conditions in an accelerator environment restrict the choice of usable materials.

I. INTRODUCTION

The use of materials for microwave absorption is a topics of interest to various scientific communities. Among those interested in special materials are accelerator builders, microwave tube experts, fusion device builders and materials scientists from various areas of technology.

In the past, most of the design of accelerator components that dealt with microwave absorption relied on known and tested materials first used in other areas of technology and which were not specifically developed for accelerator applications. Microwave losses in a number of traditional materials (silicon carbide or ferrites, for instance) have been utilized in accelerator-related systems without a thorough analysis of the physics of loss processes and without simultaneously considering other essential properties of the lossy materials, such as structural properties, thermal conductivity, radiation resistance, temperature dependence of the microwave absorption, vacuum compatibility, broad frequency bandwidth as well as manufacturing and reproducibility issues.

The incomplete analysis of the field of microwave absorbers could lead to difficulties in the construction and operation of future machines, because many new accelerator projects are being designed and built with key performance parameters strictly dependent on the availability of good microwave absorbers (for instance, higher-order-mode control in various types of accelerators, such as linear colliders and high-current circular machines). Thus it seemed that a useful activity would be a workshop which would gather experts from various fields of science and technology who could interact with each other and address issues in materials science and new technologies related to materials for microwave power control which can have a great impact on the construction of new machines.

In accelerator laboratories, the dissipation of microwaves is often considered a necessary evil (for example, in lowering the overall efficiency of high-power microwave systems and dissipating as heat the precious high peak power of pulsed klystrons), and it has not received adequate attention because of its negative connotation. Low losses, high accelerating fields and high efficiencies are of primary importance in accelerator physics, and the development of new microwave-absorbing materials for accelerators and similar systems has not been given a high priority.

The author's experience with the consequences of the incomplete knowledge in this area turned into a special project of fast development of a new material, and into a determined effort to prevent other researchers' future misuses of materials in this context. The workshop on Microwave-Absorbing Materials for Accelerators (MAMA) is an attempt to provide better understanding of the problems related to these special materials and to increase cooperation and communications among scientists and engineers with widely different backgrounds.

In this paper an attempt is made to give a general flavor of the problems and subjects treated during the workshop. Due to the large number of contributions, this single paper cannot do justice to all the authors and participants, but should serve as a stimulus for those interested in pursuing the interest further and in working with other experts on the subject. The author apologizes for the necessary inadequacy of the report.

II. GENERAL PROPERTIES OF ABSORBERS

Among the particle accelerators that are being planned or designed and which require specialized absorbers, the most important are electron (or positron) accelerators, because of the critical importance of controlling beam instabilities due to higher-order-mode power generation.

The presence of absorbers is necessary because the charge bunches traveling along the non-uniform cross section of the accelerating microwave cavities interact with the metal structures, depositing a fraction of the energy into cavity modes other than the fundamental (usually the TM_{010} mode). In most cases, these higher-order modes (HOMs) are damped by the ohmic losses at the cavity surfaces, but when either normal conducting cavities have small dimensions or the cavities are superconducting (thus, with very long decay times of the energy stored in HOMs) the modes can feed back onto the beam and affect its trajectory, leading to uncontrolled beam instabilities [1], especially in extreme cases of high currents or particularly sensitive system geometries.

These instabilities must be avoided by extracting the HOM power and disposing of it in a suitable way. In some cases this power is extracted to room temperature before being dissipated. It is, however, desirable to convert the power into heat before crossing physical boundaries. Transporting microwaves across transitions makes the absorption less controllable and the engineering of the absorbers much more problematic.

A general approach to the problem of absorbing microwaves in accelerator systems can be visualized in figures 1 and 2. Figure 1 shows how feedthroughs carrying RF across vacuum boundaries make the design difficult and the operation of accelerators hazardous (brazed joints that must deal simultaneously with high RF power, broad bandwidth, vacuum and/or coolant interfaces).

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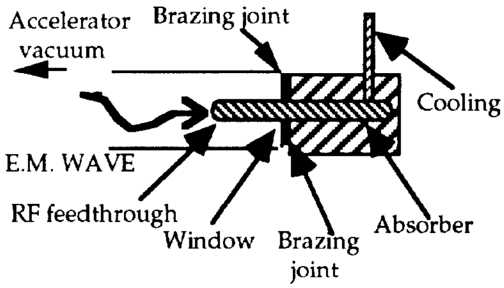

Figure 1 The geometry of extraction of microwave power from accelerators stems from unreliable absorbing materials used in the past, which require isolation from the accelerator vacuum and feedthroughs to carry the RF across boundaries.

Generally, new load designs might be possible, and compact absorbers could be made to work under vacuum or controlled atmosphere and without water cooling systems which make the system narrow banded, complicated by the cooling system. Although these loads have been in the past used extensively and with a good track record [2], they are potentially prone to vacuum accidents. Compact loads of high thermal conductivity materials with dielectric properties independent of temperature could in principle run without cooling (dry loads) and only with minor protection against thermal runaway up to several hundred degrees centigrade [3].

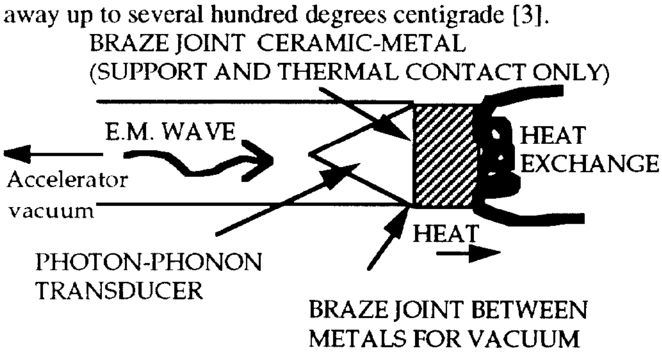

Figure 2 A better geometry for absorption involves the use of vacuum-compatible lossy materials placed inside the accelerator vacuum.

Similar problems of high-power loads compatible with ultrahigh vacuum and having to work under varying high-power loading conditions are experienced in Tokamak fusion devices, in which the plasma is heated by microwave power and termination must be placed inside the toroidal structure [4]. Due to the varying load as the plasma heats up, materials with temperature independent absorption and with very high thermal conductivity would be desirable for this application. One special requirement for these materials is the resistance to radiation, a property which is also of great importance in any accelerator installation [5].

III. MICROWAVE-ABSORBING MATERIALS AND THEIR PHYSICAL PROPERTIES

Because a thorough understanding of the phenomena involved in microwave absorption is important in choosing the proper material for a specific application, several talks were given at the MAMA workshop on the physics of absorption. Newnham, Jacobs, Rodrigue, Booske, Galstjan and Katz [6] described several loss phenomena. In general, losses can be thought of as photon-phonon scattering processes. Whereas photon-phonon scattering mediated by polarization effects in crystals, or by ionic transport within crystals or at the grain boundaries of crystallites, or by materials with semiconducting properties, yields temperature-dependent losses, one loss mechanism which has a weak temperature dependence is the ohmic effect at radio frequencies in metals, where the electron population in the conduction band is never zero and the anomalous skin effect prevents major loss variations at low temperatures.

Other loss mechanisms can be ascribed to magnetic field effects, such as magnetization losses in ferrites [7], which however are affected by the external bias fields. The materials can have remnant magnetic field and the losses are nonlinear. The linearity of the ohmic losses in the conducting grains of an artificial dielectric lead to materials which are insensitive to large external magnetic fields, and can tolerate large amounts of dissipated power. Ferrites cannot be easily operated at high power levels, due to the poor thermal conductivity (typically few W/[m · K]), the large dissipation per unit volume and the fact that they could heat up above the Curie point and give varying absorption properties. Ferrites have been used successfully in many microwave absorption applications and a large amount of work exists on the subject, which makes their use very reliable. Recent work in various accelerator laboratories has advanced the understanding of such materials for these applications [8].

IV. RAW MATERIALS, CERAMICS AND MANUFACTURING PROCESSES

Ceramic materials are among the best suited for an accelerator's vacuum systems. Several of their properties are very well understood and under control [9], but in most cases ceramics have not been used in the past for their electrical properties. A notable exception is silicon carbide in various forms, the properties of which were reviewed extensively at the workshop [10]. The manufacturing problems of artificial dielectrics were addressed by Mikijelj [11], with particular emphasis on the properties of various mixtures which can give reproducible results.

The standard and advanced processes involved in the sintering of ceramics were discussed by Spriggs [12], and Guiton [13] presented data on the remarkable improvement in thermal conductivity of ceramics (AlN in particular) when processed in various ways. Special powder manufacturing results by plasma spray were discussed [14] with the possibility of controlling the purity and grain size of several metals, ceramics and alloys. Properties of carbon powders were presented by Pierson [15], as carbon in its many forms may present itself as one of the best materials for microwave absorption in specific and very constraining applications such as in accelerators.

One important issue in the design and construction of absorbers for special applications such as accelerators is the problem of making consistent and reliable brazing between the absorbers and the surrounding metals of the vacuum chamber. Extensive work is needed in this area, and Greenhut covered many of the issues [16]. The necessity of vacuum compatibility of these materials was outlined by Dylla [17], with arguments which favor ceramic materials over other types of absorbers. The special ceramic compounds used for ferrite absorption and the manufacturing methods associated with them were described by Blankenship [18].

One of the most complicated and unresolved issues in the manufacturing of lossy materials is the reproducibility of results and of material properties. A variety of materials parameters and their interconnections play a role in the production of materials for microwave absorption [19]. Whereas most manufacturers produce ceramics for their structural properties, nowadays electrical and thermal properties are becoming important and the producers of powders and finished products are not fully aware of the need of some consumers. This workshop provided an opportunity for users and manufacturers to get together and let each other know their needs and capabilities. The work of Ho [20] is of great importance to the whole community because it shows how materials with nominally the same composition can have vastly different properties from the electrical point of view. This problem must be traced and controlled all the way from the powder fabrication processes and producers to those who make final use of these materials so that a concerted improvement can be achieved. An important aspect of this process of improvement is given by the accuracy and precision of the measurement of electrical properties of these materials. Weil [21] and Hutcheon [22] addressed some of these issues. The design of complete absorbers will benefit in the future by the existence of computer codes that can both simulate special materials and at the same time include lossy dielectrics in the computations [23]. These tools will eventually provide great flexibility in the use and design of absorbers in accelerators.

V. CONCLUSIONS

In several laboratories around the world materials have been used for damping of higher-order modes in accelerators or for absorption of microwaves in general. Often the lack of availability of materials for absorption within the accelerator or microwave tube vacuum has limited the performance of the systems designed around them. The availability of increasingly better ferrites and artificial dielectric materials will certainly provide new ideas and solutions to accelerators builders who will benefit from the existence of improved microwave absorbers.

A very close collaboration between those who build accelerators and materials scientists in national laboratories, industries and academic environments all over the world is not only desirable but necessary. The development of tight manufacturing and measurement techniques and of procedures must be achieved in this area in order to obtain a wider and more reliable use of these special materials.

Due to the diverse requirements that such materials must satisfy, all the problems related to them must be addressed simultaneously. The use of materials which only satisfy the electrical requirements cannot lead to more complicated application problems. The approach of finding ideal materials for each application requires close collaboration among scientists with varied and diverse knowledge and skills. The MAMA workshop has attained this goal and will provide again in the future an arena for these diverse disciplines.

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REFERENCES

All references below (unless otherwise indicated) are included in the *Proceedings of the First Workshop on Microwave-Absorbing Materials for Accelerators (MAMAs),* (I. E. Campisi and L. R. Doolittle, Eds.) CEBAF, Newport News, Virginia, February 22—24, 1993. (In print.)

[1]J. J. Bisognano "The need for MAMAs in accelerators and tube technology"; R. Rimmer "Extraction and absorption of higher-order modes in room temperature accelerators"; H. Padamsee "HOM control in superconducting cavities"; J. Calame "Applications of microwave absorbing materials in microwave tubes".

[2]L. Nielsen "Engineering issues in microwave loads design".

[3]I. E. Campisi, et al."CEBAF HOM loads".

[4]H. K. Park "Design criteria and materials for ultra-high broad band microwave absorbers for scattering experiments in tokamak plasmas".

[5]D. G. Howitt "Radiation-induced transformations in materials in electron accelerator environments".

[6]R. E. Newnham "Fundamental interaction mechanisms between microwaves and matter"; I. S. Jacobs " Metal-dielectric composites (artificial dielectrics)"; J. H. Booske "Effects of high-power microwave fields on ionic transport in ceramics and ionic crystalline solids"; E. A. Galstjan "The effective electrodynamic parameters of a medium impregnated by two-layer spherules"; J. D. Katz "Microwave processing of ceramics".

[7]G. P. Rodrigue "Theory of electromagnetic properties of ferrites".

[8]W. H. Hartung "Measurements of the microwave properties of some absorbing materials".

[9]S. A. Wise "Ceramics: structural, thermal, and vacuum properties".

[10]R. F. Davis "Polytypism, process routes, and microstructures and the effect of these parameters on the electrical properties of silicon carbide"; G. Fischman "Thermo-mechanical properties of silicon carbide".

[11]B. Mikijelj and I. E. Campisi "Development of an artificial dielectric ceramic for use at CEBAF".

[12]R. M. Spriggs "Ceramic sintering".

[13]T. A. Guiton "Improving the thermal conductivity of ceramics".

[14]R. Cheney "Plasma manufacturing of fine metal and ceramic powders".

[15]H. O. Pierson "Carbon powders: properties, processing and applications".

[16]V. A. Greenhut "Fundamentals, techniques and recent developments in ceramic-metal joining and metallization".

[17]H. F. Dylla "Vacuum properties of materials".

[18]A. C. Blankenship "Commercial ferrite manufacturing".

[19]I. E. Campisi , *Proc. Am. Cer. Soc. Meet.*, 1993 (in print).

[20]W. W. Ho, M.R.S. Symp. vol. 124, 137—148 (1988).

[21]C. M. Weil "Dielectric and magnetic properties measurements: NIST Metrology Program".

[22]R. Hutcheon "Dielectric and magnetic properties measurements: data from AECL".

[23]D. Shenton "Computational codes for load design".