New Materials and New Challenges in Vacuum Technology

Alan R. Krauss, Guest Editor

There are times when technological or scientific progress is blocked for want of a breakthrough in a key area, just as there appear to be instances of a problem and its solution emerging simultaneously and independently. Upon closer inspection, however, this latter happy state is usually the result of long, hard work by people who had the insight to develop a solution before their peers were aware of the existence of a problem. At the moment, there are a number of convergent events occurring in vacuum technology which in all likelihood will have as profound an effect as the development of ultrahigh vacuum (UHV) technology in the late 1960s and early 1970s. These developments may be viewed as challenges posed by the requirements of certain technologies, or as a series of breakthroughs which will lead to new opportunities. Materials and materials processing or coatings are the key factors in most of these new developments, just as new pump and seal designs, and new vacuum practice were responsible for the development of UHV (10^{-9}–10^{-11} torr) technology.

In particular, aluminum is emerging as a material which may replace stainless steel for applications where the ultimate in vacuum is required. By suitable treatment, pure aluminum and aluminum alloys can be made to produce static outgassing rates more than 10 times lower than stainless steel.[1] Systems capable of reaching a base pressure in the extremely high vacuum (XHV) range of 10^{-12}–10^{-13} torr, such as those described in this issue by H. Ishimaru, are now commercially available. These systems are typically made of pure aluminum (for the chamber) and carefully selected aluminum alloys for appropriately matched thermal and mechanical properties in fittings and flanges. Sealing surfaces are usually coated with TiC. All exposed aluminum surfaces are subjected to a special process which produces a very dense, thin, hydroxide-free aluminum oxide coating.

Synchrotrons, especially dedicated synchrotron light sources, have unique vacuum problems extending beyond the need for a low base pressure. The beam lifetime is determined not by the base pressure (beam off), but rather by the pressure obtained when the beam is on. As a result of photon- and electron-induced desorption, this pressure may be several orders of magnitude higher than the base pressure. High pumping speeds are therefore required, although the location of the synchrotron magnets and required magnet field uniformity make it difficult to provide sufficient lumped pumping speed to obtain the necessary operating pressure of 10^{-9}–10^{-10} torr. The photon beam itself provides a cleaning process. However, in order to use the beam-induced desorption to remove the residual gas trapped in near-surface layers, it is first necessary to obtain a beam. The surface must therefore be preconditioned to provide as little gas burden as possible. A number of techniques, including baking, gas discharge and chemical cleaning, have been employed. The latter technique applies primarily to preparation of sections prior to assembly. For stainless steel, and especially for aluminum chambers, the formation of water-containing oxide layers upon exposure to atmosphere requires that once treated, the chamber section be vented as little as possible, and that dry nitrogen be used as the vent gas.

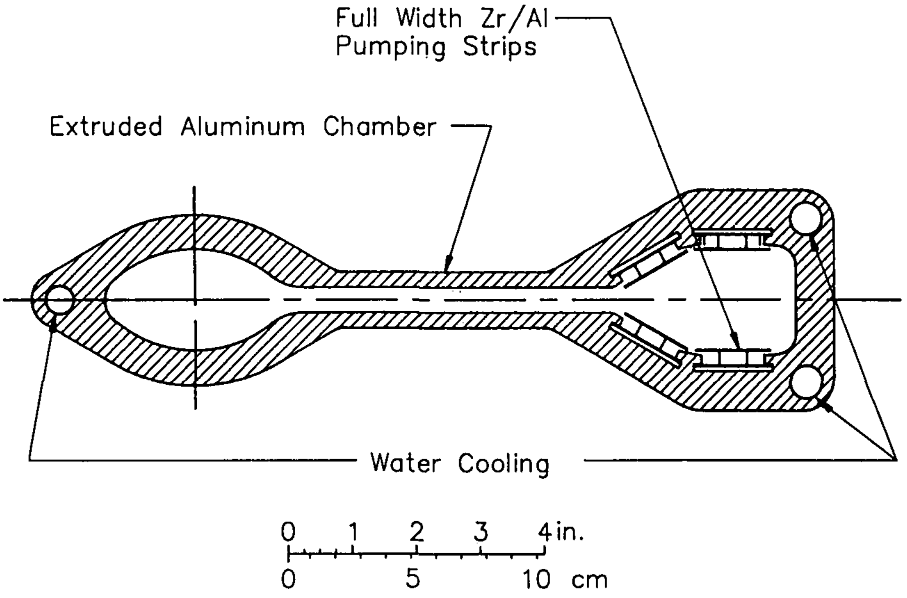

Figure 1. Cross section of the vacuum chamber for the Argonne National Laboratory Advanced Photon Source. See related article on the APS in this issue in the Research/Researchers section.

Several recent machines have made use of strips of Zr-Al alloy running around the circumference of the machine. This alloy acts as a nonevaporable getter (NEG) material,[2] providing pumping speeds in excess of 1,000 l s^{-1} m^{-1}. The first machines to make use of NEG pumps simply placed the strips inside the beam chamber. More recent designs[3] make use of a separate pumping chamber to house the NEG strips, communicating through a relatively narrow channel to the beam chamber. The resulting vacuum chamber has a complicated cross section (Figure 1) which is difficult to fabricate in stainless steel but which may be extruded in aluminum. Unfortunately, the photon-and electron-induced desorption cross sections for aluminum are higher than those of stainless steel, initially by a factor of 100, but dropping with continued beam exposure to a factor of approximately 10.[4,5]

In the newer machines using insertion devices which produce highly collimated radiation, this problem is treated by directing the photons onto selected areas made of materials with lower photon- and electron-induced desorption yields. However, beam alignment is critical in such an arrangement, and retuning the machine is likely to be accompanied by a need for reconditioning the photon beam dump areas. Furthermore, it is essential that photons not be allowed to scatter onto areas other than the designated sections. To some extent these problems may be reduced by applying special coatings with low photoelectron yields to the exposed aluminum surfaces. Although there are currently no machines with an overall coating, several synchrotrons make use of TiN coatings in selected areas to reduce the resonant gas desorption process known as "multipactoring." Some of these questions are addressed in this issue in the articles by J. Schuchman and by K. Moriyama.

Vacuum materials play a major role in the performance of thermonuclear fusion devices. Interactions between the plasma and the surface of materials exposed to the plasma lead both to the erosion of structural components and to contamination of the plasma and quenching of the thermonuclear burn. Although high-Z refractory metals would seem desirable as a means to reduce plasma-induced erosion, very small amounts of high-Z impurity in the plasma result in radiative energy losses which are sufficient to prevent attaining energy break-even. Low-Z plasma impurities do not result in the large plasma energy losses associated with high-Z impurities, but for graphite (the most widely used low-Z material) trapping and desorption of cold gas inhibit the plasma performance of the device. In addition, components made of graphite, beryllium or boron are subject to sputter-induced erosion rates on the order of several meters per year. Since it is difficult to envision a design which permits the use of such thick components, short component lifetime may make the practical production of energy by a fusion process difficult to achieve, especially when maintenance is complicated by the presence of radiation associated neutron activation and trapped tritium, and in the case of Be, by the presence of toxic materials in the vacuum chamber.

Assuming the attainment of long plasma burns which produce net energy, it then becomes necessary to remove the helium "ash" resulting from the thermonuclear burn. If the helium level is allowed to exceed 5%, it will quench the burn by diluting the deuterium-tritium fuel. Consequently, it is necessary either to pump large quantities of gas containing approximately 50% radioactive tritium which must be separated and recycled into the fuel flow, or to find a way to preferentially pump the helium in the presence of a large background of hydrogen. One such pumping strategy, based on gas trapping properties at defect sites in metals, is described briefly in the final article in this issue.

In the case of the development of NEG pumps and XHV technology, the technological breakthroughs are based on new uses of materials and are having a direct impact on the vacuum design of new research devices. In the case of magnetic confinement fusion research, the practical limits of the technology are largely determined by materials properties; the problems have been identified, and a large part of the solution will have to be based on ingenious use of materials.

Acknowledgments

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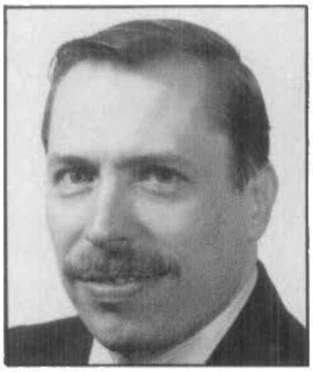

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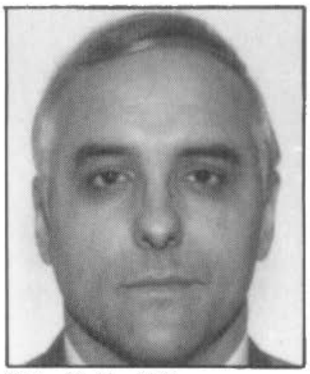

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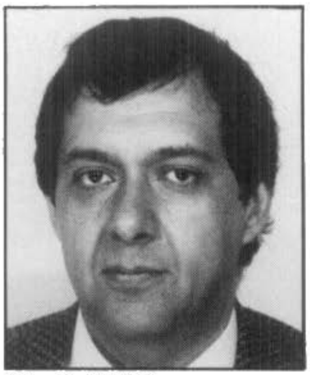

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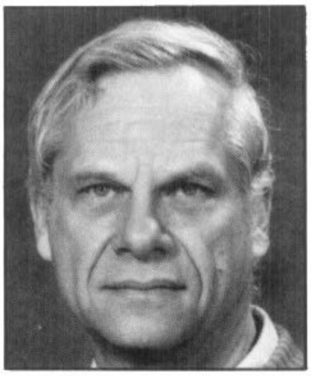

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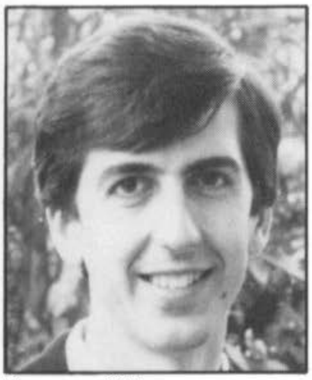

Francesco Mazza

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damental studies of neutron radiation damage in metals and post irradiation tests of reactor fuel rods. Since 1984 he has participated full time in Argonne's Fusion Power Program. He has been responsible for the engineering design of fusion impurity control systems for the INTOR design project and now participates in the ITER (International Thermonuclear Experimental Reactor) project. Mattas is a graduate of Yale University (BA, 1969) and holds a PhD in metallurgical engineering (1974) from the University of Illinois.

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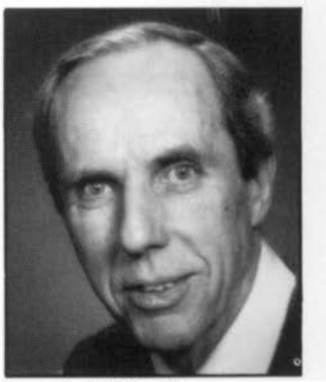

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