SUMMARY

Beam processing and material analysis

Accelerators have an important role to play in the processing of materials. In this context they have had a significant impact on the economy of developed countries and have contributed in a major way to the development of high technology products.

Ion beam processing is a particularly powerful and versatile technology, which can be used both to synthesize and modify materials, including metals, semiconductors, ceramics and dielectrics, with great precision and control. Ion beam modification of materials involves using an ion beam to alter the composition, structure or properties of the near surface of materials. Ion implanters are now used in the manufacture of advanced microchips produced by the semiconductor industry for computers, information technology and communications systems. It is estimated that to date 7000 ion implantation accelerators are in use in the semiconductor industry alone. Ion implantation requires special accelerators, able to implant ions of most elements of the periodic table at high beam currents (>> 1 mA), scan the beam uniformly over a sample and typically cover energies from the keV to MeV range.

In addition to wide applications in semiconductor industry, this technology is used for deposition of thin film coatings for improving various tribological properties, such as wear, friction and corrosion. Ion beam technology has and will continue to make significant contribution in “niche” markets ranging from specialized tools used in industry, to surface treatment of intricate devices used in the medical field. For example, titanium alloys containing aluminum and vanadium have excellent biocompatibility, good strength and corrosion resistance. Nitrogen implantation in specific doses improves the wear performance of these devices by a factor of 1000, thus extending the lifetime of titanium-based hip joints.

In addition to traditional ion implantation technique, the research is going on the development and applications of various methodologies for ion beam deposition, like ion beam mixing, ion-beam assisted deposition, cluster and molecular beam surface modification, etc. The ion beam processes will continue to play an important role in further understanding and refinement of surface treatment of materials.

Different interaction processes between ion beams and material are the basis if the Ion Beam Analysis (IBA) techniques. The most common IBA methods are PIXE (Particle Induced X ray Emission), RBS (Rutherford Backscattering Spectrometry), ERDA (Elastic Recoil Detection Analysis) and NRA (Nuclear Reaction Analysis). All elements can be detected with the IBA techniques. NRA and ERDA are more suitable for light elements and in particular for hydrogen, RBS and PIXE are complementary. Typically, small electrostatic accelerators of about 2–3 MV on terminal are used although lower energy machines may be used. There are about two hundred facilities worldwide active in the field of material analysis by accelerator-based methods. Although most of them are located in developed countries, more than twenty developing countries have such facilities mostly in their research institutions. A modern IBA laboratory is described in the paper by J. Simčič et. al. (IAEA-SM-366/140).

Among the many fields of IBA applications, the most widespread are applications in materials development, environmental pollution studies, biomedical research, geology and archaeometry. Because of the depth information that they provide, the three IBA techniques, RBS, ERDA and NRA are a valuable complement to more conventional surface analytical techniques, and they have some unique features which make them indispensable for certain
problems. These techniques allow concentration depth profiling with depth resolution from few nm to several µm.

Several papers presented at the symposium deal with the use of ion beam techniques for characterization of materials. In papers given by Dr. Jaksic et. al. (IAEA-SM-366/133) and by Dr. Arafah et. al. (IAEA-SM-366/136) materials used in solar cells are studied, this research is helpful for producing more efficient solar cells. A paper given by G.R. Dos Santos (IAEA-SM-366/131) studies high Tc superconductors by using ion implantation and positron spectrometry. High Tc superconductors are advanced materials with important applications in e.g. the fields of power transmission and magnet technology.

Due to their non-destructive character, IBA techniques constitute a powerful tool for the knowledge, the conservation and the restoration of cultural heritage. Invaluable works of art can be studied in situ by using external beam PIXE or dated and analyzed by Acclerator Mass Spectrometry requiring only milligram amounts of sample material. Among accelerator based analytical techniques, AMS is the most sensitive trace analysis technique. Trace impurity sensitivities of parts per trillion have been realized with the AMS technique.

Papers presented by B. Constantinescu (IAEA-SM-366/139) and F. Ager et. al. (IAEA-SM-366/141) describe the use of ion beam techniques in archaeometrical and environmental studies.

With the advent of accelerators with energies in the range of up to few MeV and high beam currents (of the order of 100 mA to 1 mA) applications involving the use of neutrons produced by accelerators are becoming more prominent. These include the highly important field of the detection of explosives and contraband. Higher energy accelerator sources of spallation neutrons offer intense neutron fluxes for many applications in interdisciplinary fields such as nuclear waste transmutation and energy production. In a paper by S.A. Pereira (IAEA-SM-366/101) an energy amplifier, based on an idea by C. Rubbia, which utilizes a spallation neutron source is discussed. A novel design concept for generating mono-energetic fast neutrons is described by C. Franklyn et. al. (IAEA-SM-366/114).

Radioisotope production and medical applications

Accelerator produced short lived radioisotopes are widely used in nuclear medicine because of the reduced dose to the patient. These include isotopes for Positron Emission Tomography (PET), such as $^{18}$F, used in diagnosis and pharmaceutical research, development and testing. Others include $^{67}$Ga in citrate, $^{82}$Rb/$^{81m}$Kr generators for lung imaging and various forms of several iodine isotopes in particular $^{123}$I. The radiopharmaceuticals using these isotopes produce maximal diagnostic information with minimal radioactive waste involved in their production. New accelerator methods for radioisotope production are being developed, as alternatives to reactor produced radioisotopes. Radioisotopes for research such as the positron source $^{22}$Na, are also produced. These radioisotopes are used in both pure and applied research into the condensed matter. The machines required for the production of these isotopes are typically cyclotrons producing proton beams of typically 15–60 MeV. Proton accelerators in the energy range 50–200 MeV are increasingly being used for also cancer therapy (e.g. eye melanoma). Several papers presented at the symposium deals with isotope production and cancer therapy with protons. The papers presented by D.T.L. Jones (IAEA-SM-366/123) and M.R. Nehodu (IAEA-SM-366/122) describes a proton accelerator used for cancer therapy. The development of small cyclotrons by e.g. J. Chai et. al. (IAEA-
Applications of synchrotron radiation

Light sources are versatile tools for scientific investigations. A synchrotron source is a powerful light source based on modern accelerator and magnet technology. Electrons are accelerated to several GeV, injected and kept circulating for several hours in a storage ring. Due to the interaction with specialized magnet systems the electrons emit synchrotron light in the wavelength range from infrared radiation to X rays. The emitted radiation is transported, to experimental stations, along special beamlines connected to the storage ring. In this way the light can simultaneously be utilized by several user groups. The applications of synchrotron light range from crystallography to trace elemental analysis for medical, environmental and archeological research, and from machining of micro mechanical parts to novel and powerful radiographic methods. A few examples will illustrate the usefulness of synchrotron light. The field of macromolecular crystallography has experienced an explosive growth during recent years. Synchrotron based techniques locate the position of atoms in huge protein molecules. This information is of great importance for the understanding of the human genome. A more direct impact is the design and manufacture of new anti-viral drugs. Each new drug requires structural studies of several hundreds of macromolecules. Synchrotron based X ray fluorescence microprobe techniques explore the chemical composition of samples down to a scale of a few millionths of a millimeter giving a powerful tool for trace elemental studies of medical, environmental and historical samples. Synchrotron light can be used not only for scientific research but also for industrial fabrication of ultra miniaturized products. Photolithographic techniques utilizing short wavelength ultraviolet light are used for manufacturing mechanical parts down to the size of hundredths of a millimeter. The potential applications of this technique impact many areas from the automotive industry to novel medical devices and applications. In a paper by S.M. Simabuco et. al. (IAEA-SM-366/157) the application of synchrotron radiation for the analysis of biological and environmental samples is described.

As of today there are 45 operating synchrotron sources, 11 under construction and 16 proposed in 20 different countries around the world. Even taking in to account new sources being proposed the rapid growth of the user community will outpace the available supply of synchrotron light for a foreseeable future.

IAEA activities concerning utilization of accelerators

During the past two decades the IAEA has assisted many national laboratories in its Member States in various fields of accelerator applications. This assistance has been realized through both regional and national Technical Co-operation (TC) projects, Co-ordinated Research Projects (CRPs) and other IAEA activities. The IAEA has provided several laboratories in the developing countries with low energy accelerator systems. In more occasions the existing accelerator systems have been upgraded, and in many cases only specific equipment for particular application has been provided, together with fellowships and expert visits. Several IAEA sub programmes/projects are related to accelerator utilization. They are supporting the use of electron and ion accelerators for electron and ion beam processing, material analysis, radioisotope production and other medical applications.