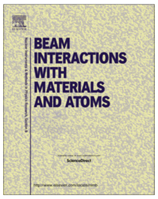
Nuclear Instruments and Methods in Physics Research B 331 (2014) 48–54

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb



Ion beam analysis: New trends and challenges

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ARTICLE INFO

Article history:
Received 24 September 2013
Received in revised form 2 February 2014
Accepted 2 February 2014
Available online 13 March 2014

Keywords:
Ion beam analysis
PIXE
Channeling
EBS
Total IBA
Imaging

ABSTRACT

The development and diffusion of IBA analysis are shortly reviewed paying attention to most competitive and recent advances produced within the IBA community. The paper remarks the potential that IBA maintains in terms of analytical capabilities and points out some future perspectives of the field in terms of innovation and competitiveness.

1. Introduction

Since the onset of human civilization the ability to produce new materials has been the booster of all our societies assuring them health, power and wellness. When the trial and error processes, that for hundreds of thousands of years had been behind the development of new materials, have been replaced, thanks to the scientific advancements, by the analysis and test procedures, the production of materials with specifically required properties has become possible and routinely pursued. Technological materials are now a strategic theater where many scientific disciplines are producing advancements and refining methods so to offer the fastest, more efficient and economically rentable ways of producing and exploiting such new materials. It is about half a century that the ion accelerators have started to find application in materials science as analytic [1,2], testing and production tools. This is because the ion beam parameters can be varied and controlled in a rather wide range which allows the selection of the most appropriate conditions (type of ion, energy, current, flux, fluence, beamsize, etc.). Thus, the ion–solid interaction can be adjusted, from weak or slightly perturbative (ideal for the nondestructive analysis [3]), to strong (able to modify substantially the material structure and properties [4,5]). Particle accelerators have proved to be competitive in this scientific/technological domain and have given rise to two applied branches, namely ion beam analysis (IBA) and ion beam modification of material (IBMM). Ion accelerators, in particular the electrostatic ones, have also evolved in the last 50 years, from machines adapted to fundamental physics (essentially nuclear physics) to a class of accelerators specifically designed for material characterization and modification. While recognizing the relevance of IBMM, the scope of this paper is to focus on IBA only, reviewing its current outstanding applications and foreseeing future perspectives.

There is a plethora of analytical techniques for the characterization of materials [6,7], which can be divided from a practical point of view as a function of the probing or detected particle [6]. In this general sense, ion beam techniques are those where the incident particle is an energetic ion. Thus, IBA corresponds to a collection of techniques based on the selective detection of either particles or electromagnetic radiation produced from the interaction of a probing ion with the constituents of an (a priori) unknown target (see Fig. 1). Due to the origin of IBA techniques, normally linked to nuclear physics experiments (in the MeV range) [1,2,8], IBA has been traditionally restricted to a main group of general methods comprising Rutherford backscattering spectrometry (RBS), elastic recoil detection analysis (ERDA), nuclear reaction analysis (NRA, with the particular case of particle-induced gamma-ray emission or PIGE), particle-induced X-ray emission (PIXE), and channeling [9]. However, this collection can be easily extended according to different criteria and a general glossary of ion beam assisted techniques can be found in the recent review from Jeynes and coworkers [10]. Each of the IBA techniques can be tailored around a particular reaction channel that is, in general, specific

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http://dx.doi.org/10.1016/j.nimb.2014.02.013

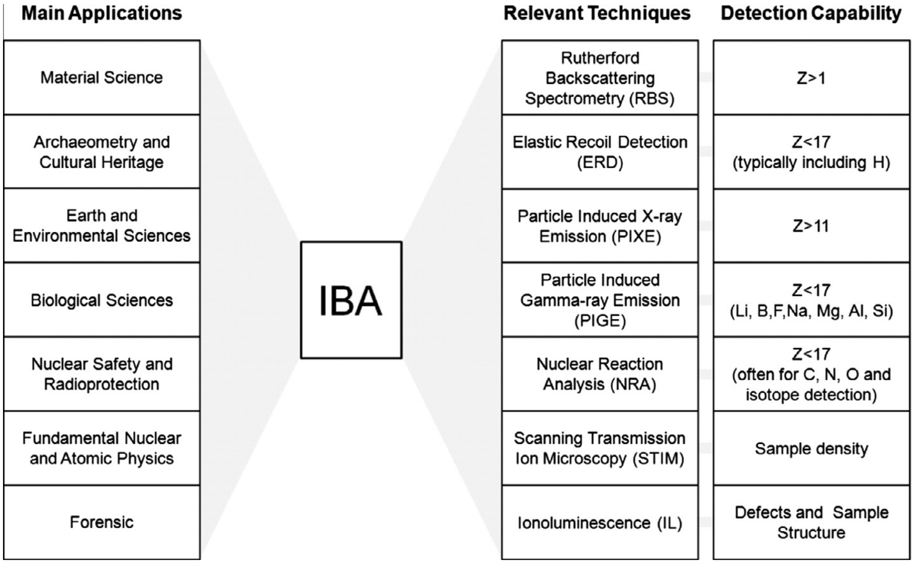

Fig. 1. Synopsis of the IBA techniques, their detection capability and the main applications.

for the detection of certain atomic species. The large diversity of ion–solid interactions results in a sensitivity that can be orders of magnitude different from one reaction channel to another (e.g., the RBS and PIXE cross sections are very different even when the same beam-sample conditions are used). Nevertheless, the great potential of IBA is that there is a cluster of techniques capable of covering the whole periodic table of elements with the following main features:

- Providing compositional information with good elemental detection (mass identification) and quantification of concentration with good sensitivity (from 0.1 at.% to few ppm).
- Fast acquisition times (10–20 min) and nondestructive character (generally).
- Extended 2D mapping capability with high lateral resolution (down to about 30 nm) and depth profiling with a resolution that can go below 1 nm.

The IBA success is due to the dedication and efforts of a broad international community that has been capable of strong interactions with other scientific disciplines, has shown an endless motivation for development and innovation and remarkable attitude to cooperation and networking. Today the community counts on almost 200 centers [11] distributed worldwide, with peaks in the 28 EU countries, in the USA and Japan but anyhow accessible in all continents also thanks to several very efficient cooperation schemes [12–15]. Many types of facilities are into operation and cover a terminal voltage range from below 1 MV up to 20 MV and quite a few are being installed [16,17]. It is worth observing the coexistence of very old (more than 50 years!) and new machines, which is a proof that the innovation in the field is at the same time motivating the expansion of the IBA community and allowing to keep even the oldest machines at a level of competitiveness sufficient to assure a productive activity.

2. Remarkable applications of IBA

Characterization techniques represent a challenge in terms of the ultimate achievable resolution and sensitivity. Although many of the analyzing methods can be considered classical, they have considerably evolved in the last decades to provide better performance, with some notable cases that have became commercially available (e.g., compact microscopy or analytical equipments). IBA has been also part of this innovation and development, taking advantage of the powerful, and sometimes unique, features of the techniques. Moreover, IBA have proved to play a remarkable role in some particular problems which are somehow paradigmatic. Next, we summarize some of these applications where IBA has had a remarkable use.

2.1. Application of microbeams to cultural heritage: the AGLAE example

In the past years external ion beams [18] have been implemented by many laboratories to fulfill the demand coming from archaeologists, curators, conservators, art historians. Such beams can couple the great advantage of the ease of manipulation and conservation of the sample with a convenient work distance (2–4 mm), and beam parameters on sample. Energy losses and straggling in the order respectively of 10 keV (1σ) and 2 keV (1σ) and beam dimension of the order of 10 μm (full width at half maximum, FWHM) in both X and Y directions are the actual limits [19]. In any case 2–3 times higher values are quite convenient for the solution of a broad range of analytical problems and are unique for some peculiar applications. The competition of bench and portable techniques, as well as of synchrotrons has become very strong; however the potential of the cluster of nondestructive IBA techniques that can be exploited in a single irradiation and the innovation, especially in elemental imaging, maintains IBA quite competitive in field of Cultural Heritage (CH) analysis. AGLAE (Accélérateur Grand Louvre d'Analyse Elémentaire) [20] has been the archetype of IBA applications to CH for the past 23 years regarding both the technical [21] and methodological development [22], as well as the opening of research lines (too many to report!). Its great success has been determined by the fact that it is the first and only accelerator built inside a museum (the most visited museum in the world indeed) and that the Centre de Recherche et de Restauration des Musées de France (C2RMF), which runs the accelerator, has been a pioneer in the establishment of coordination and access schemes with the programs Labs-Tech, EU-Artech and Charisma [13] launched in the three past EU framework programs. The facility is now undergoing a complete refurbishment and has already produced a substantial innovation in the detectors set up [23] and the sample imaging [24]. The New-AGLAE project will