ION BEAM APPLICATION TO MATERIAL ANALYSIS IN GHANA: PROBLEMS AND PROSPECTS

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ABSTRACT

In 2016, Ghana's with assistance of International Atomic Energy Agency (IAEA) installed a 1.7MV 5SDH-2 Pelletron accelerator donated by Government of Netherlands through a technical co-operation agreement. A new beam line is installed on the 15degree port at the high energy end of the accelerator and connected to an RC-43 multipurpose chamber with IBA capability. This study provides a summary of various research works carried out at the Centre to demonstrate the versatility of the installed system vis–a-vis the challenges of operating such a sensitive analytical facility in a developing country like Ghana. The limitations of the installed system are identified and strategies to overcome these difficulties in order to expand the utilization of the accelerator are presented and distributed.

1. Introduction

The accelerator, installed in Accra, utilize ion beam techniques especially Particle Induced X-ray Emission, Rutherford Backscattering (RBS), Nuclear Reaction Analysis (NRA) and Elastic Recoil Detection (ERD) to address issues related to elemental concentration in industries, health and allied sciences, archaeology, agriculture and also to train students.

The accelerator uses hydrogen or helium ions, accelerated to the accelerator terminal, stripped in a gas canal to positive charge state and further accelerated to the other end of the tandem. The high energy beam is bent through 15^0 by a switching magnet into a beam tube onto target inside an NEC scattering chamber. The chamber is equipped with a turbo pump and gate valves as well as a Silicon Drift Detector (SDD) for PIXE analysis, Silicon Surface Barrier (SSB) detector for RBS measurements, and a Sodium Iodide gamma ray detector for NRA analysis. The chamber is electrically isolated in order to be used as a Faraday cup to monitor beam current. The scattering chamber is always kept at high vacuum. The facility is equipped with a computer control console, a computer controlled data acquisition system and a remotely control sample manipulation system. Figure 1.provides a picture of the accelerator

2. Theoretical

2.1 Rutherford Back Scattering (RBS) Theory

RBS is based on the principle that the energy of scattered (elastic and inelastic) ions from the bombardment of incident helium ions with energies in the 0.5 to 3MeV range with a target nucleus depends on the mass of the target and the depth at which the scattering took place.

The depth and elemental composition of the target samples is determined from the energy loss of the ions in the target, the number and energy of scattered ions. The RBS spectra are analysed using SIMNRA (Mayer, 1997) for an assumed sample composition taking into account the effects of straggling, detector resolution, multiple scattering, etc. The stopping power which is very important in both the qualitative and quantitative analysis is defined as energy loss divided by atomic areal density of the target calculated using SRIM/TRIM (Ziegler et al. 1985; Tesmer et al., 1995).

2.2 PIXE Theory

When a vacancy is created by an incident ion in an atom, a valence electron migrates to fill the vacancy and a characteristic x-ray is emitted in the process. The energy of the x-ray emitted corresponds to the element present in the sample (qualitative analysis) whiles the counts or area under the measured peaks correspond to the concentration or level of elements present in the target sample (quantitative). The GUPIX software is adopted for the analyses of all PIXE spectra, both qualitatively and quantitatively (Maxwell et al. 1989). By analysing certified standards, the sample concentration can be determined (Campbell et al 2005).

3. Materials and Methods

Setup for RBS and PIXE

Samples and standards were pre-cleaned with dilute acetone solution, dried and mounted on a sample holder and bombarded with an incident Helium beams. The angle of incidence of the ion beam with respect to the target is 90^0. A silicon surface barrier detector with a resolution of 15keV is aligned at a scattering of angle θ of 165^0 in Cornel geometry at a normal incident angle from target for RBS analysis whiles a Silicon Drift Detector with resolution of 135eV is aligned 45^0 to the target for PIXE analysis. The beam diameter is 2mm with a current range of up to 200nA. SIMNRA software package was used to estimate the elemental constituents and compute the depth profile and thickness of the film for RBS analysis. GUPIX software package was used for the qualitative and quantitative estimation of the elemental composition of the films for PIXE analysis.

4. Results and Discussion

4.1 Thin films

Preliminary results of average elemental composition of the sample using PIXE technique which assumes homogeneity in the distribution of elements in samples is presented in figure 2. Silicon, chromium and gold peaks can be identified on the spectrum. These are the major elements present in the sample. A fitting parameter algorithm is performed by GUPIX software to quantify or relate peak area of identified elements to concentrations.

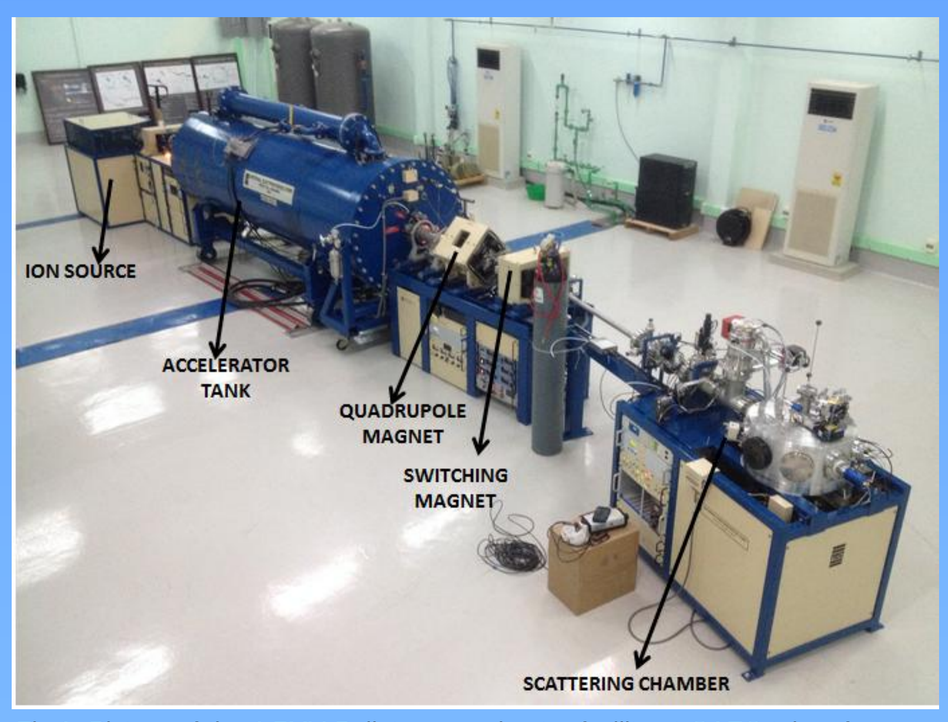

Fig.1: Picture of the 1.7MV Pelletron accelerator facility at GAEC taken from an elevated position in the accelerator hall. The top left hand side shows the ion source and the accelerator tank. The middle shows the quadrupole and switching magnets. The bottom right sowed the scattering chamber and diagnostics. Other accessories such as the SF6 storage tanks, the climate control units and the back-up electrical power supply are also visible.

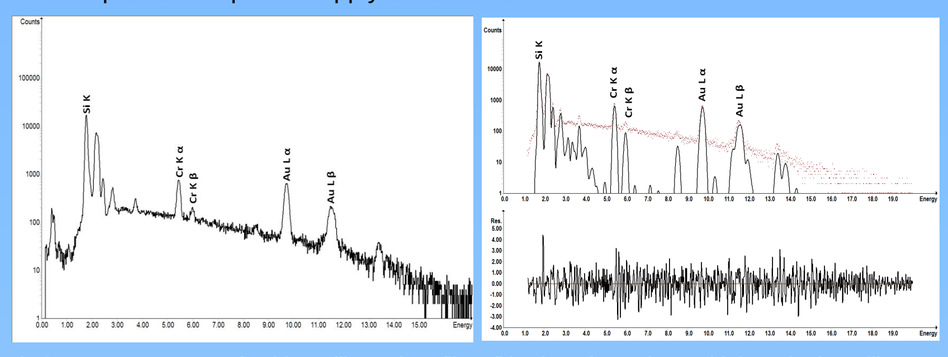

Fig 2.a: PIXE spectrum of gold on silicon glass film . (b): Fit performed on gold deposited on silicon thin spectrum using the GUPIX software package . (c) residual of the fit.

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From figure 2 and 3, three major elements (Si, Cr and Au) were found in the sample which RBS accurately resolved. The results of the qualitative elemental composition of the structure confirmed the initial results obtained from the PIXE analysis. A fit was modelled for all the three layers in addition to the surface roughness estimated by a Lorentz distribution to be $12x10^{15}$atoms/cm^2 using SIMNRA (Metzner et. al., 1997 and Hobbs et. al., 1988).

The deeper the element is buried inside the sample the higher the energy loss which lowers the scattering energy. A depth resolution of 10 nm was estimated for the RBS setup for the analysis.

The concentration of Au atoms in the sample was $476x10^{15}$ atoms/cm^2 which represents a thickness of 161nm. For Chromium a concentration value of $110x10^{15}$ atoms/cm^2; equivalent to 26.4nm thick. Thus RBS in conjunction with PIXE can be used to resolve layers and can also be used to determine layer thicknesses.

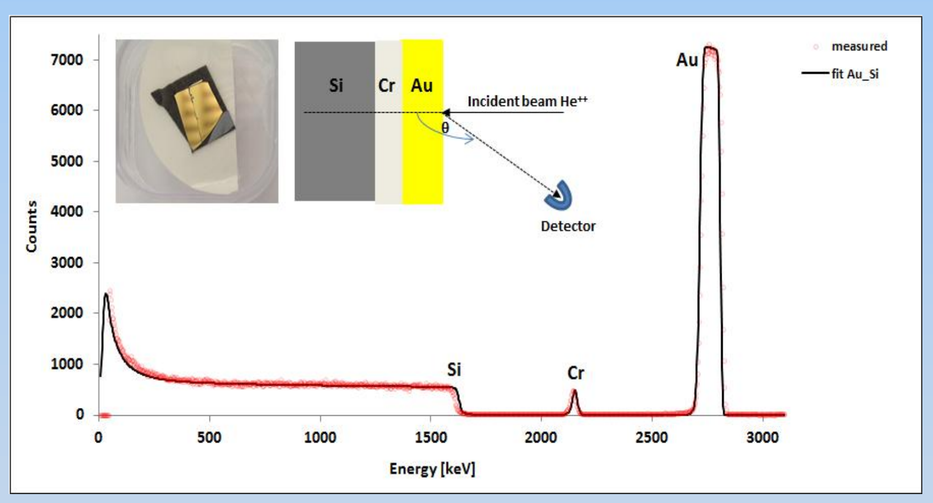

Fig. 3 RBS spectrum of gold on silicon glass film.

4.2 Cultural heritage materials

One of the issues of concern to researchers and the archaeologists is "information" and "preservation". The prime concern of the researcher is to get precise and accurate information from heritage materials without causing any visible structural deformations while the archaeologist desires his artifact to be intact before and after analysis.

Beads are important ornaments worn by royalty to adorn the neck, hands, waist and feet. These beads are also worn by ladies as a rite of passage into puberty and therefore highly priced ornaments as status symbols. We have successfully characterized a locally made glass beads. Ion beam techniques (PIXE and RBS) have been utilized to explore and provide answers to questions about the glass composition of analyzed beads, pigment composition (organic or inorganic) . The elemental spectra of a bead is shown in figure 4.

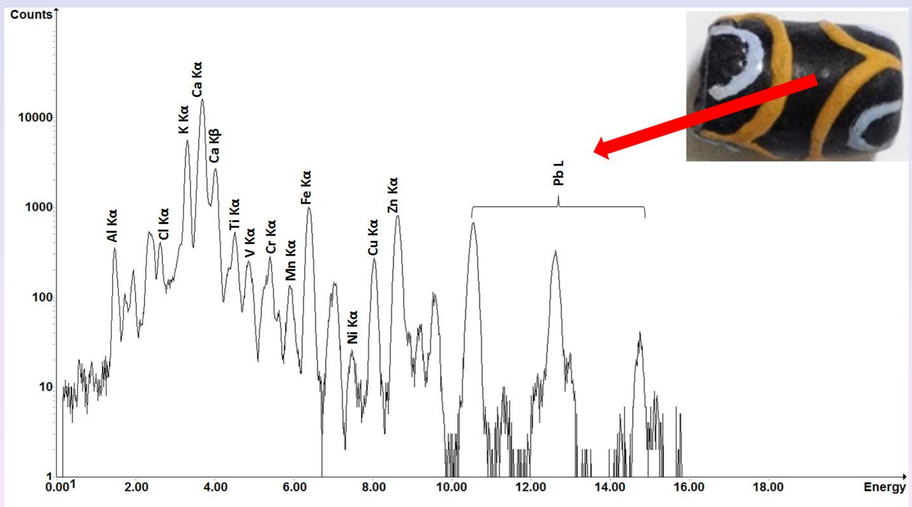

Fig. 4. PIXE spectrum of local Ghanaian bead.

4.3 Local Coins

When news coins were introduced in Ghana in 2000 there was the school of thought that the inner section of the 100 Cedi coin was made of gold. There was a rush to purchase these coins. Ion beam was used to interrogate within and outside these coins and the spectra was below obtained. Comparing the spectra we notice that elemental composition of the inner includes an additional element zinc and not gold. It is concluded that the inner ring band is most likely to be made of brass and not gold.

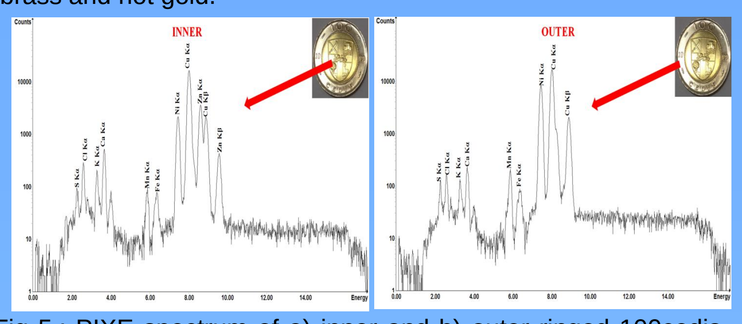

Fig 5.: PIXE spectrum of a) inner and b) outer ringed 100cedis Ghanaian coin.

5. Problems affecting utilization

1) **Unavailability of accelerator components / items locally**: Most items are manufactured abroad not locally in developing countries like Ghana. Items have to be imported for use. This may delay fixing problems with the accelerator when it breaks down, especially where replacement is not readily available.
2) **Delays with Clearing of goods at port:** Delays in clearing goods at port may affect upgrade of system or utilization. Customs clearing of items can also be a nightmare. A round table discussion with IAEA-GAEC-UNDP to resolve the differences and speed up the clearing process as undue delays have financial implications.
3) **Voltage swinging / fluctuations**: Ghana relies on hydroelectric power. During dry ./ drought season the water level in the dam is low while demand is still high. This leads to power rationing. Voltage can swing between 245V to 176V in a matter of minutes. For this reason we have implemented a vol5age range switch before an automatic voltage compensator and an Uninterruptable Power Supply (UPS) that has a range of batteries providing power for at least 2hrs before rundown. This UPS is supported by a generator. In the absence of mains power this guarantee safe run and shut down of the accelerator system when required, to prevent rubidium migration into the beam line due to sudden loss of power.

6. Future trends / needs

a) **In-air pixe setup**: In order to become truly useful to the archaeological, museums and environmental and health societies across the country and the sub-region with regards to characterization of bulky specimens (cultural heritage materials) and air filters, there is the need to build or purchase for installation an in-air PIXE setup on one of the ports of the switching magnet at the high energy end of the accelerator. It allow the generation of primary data to be used for tracking / authentication of trade in cultural heritage materials.
b) **Conferences / training workshop / seminar / fellowships:** These programs will enable cross fertilization and exchange of ideas between scientific community and technological community as it relates to IBA techniques. It will also allow for capacity building. Mentoring programs are required. Collaboration is very much welcome.

7. Conclusion

Ghana has joined the community of ion beam analytical applications. Present work demonstrates that PIXE and RBS provide useful complementary information about a layered samples, elemental distribution profiles and surface defects (roughness) in thin film samples. The addition of an in-air analysis end-station on one of the ports of the switching magnet will:

(i) allow rapid characterization of bulky archeological or cultural heritage materials

(iii) open up utilization in other areas such as aerosol research.

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