Preparation of Gold Target through Electron Vapor Deposition and "Paras" the Rutherford Back Scattering Experimental setup @ IUAC

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Abstract— Rutherford Backscattering Spectrometry (RBS) is a widely used method for the surface layer analysis of solids. Lord Ernest Rutherford first used the backscattering of alpha particles from a gold film in 1911 to determine the fine structure of the atom, resulting in the discovery of the atomic nucleus. RBS includes all types of elastic ion scattering with incident ion energies in the range 500 keV – several MeV. Usually protons, ^{4}He, and sometimes lithium ions are used as projectiles at backscattering angles of typically 150– 170∘. Different angles or different projectiles are used in special cases. Rutherford backscattering spectroscopy is employed to detect the impurity present in target material and to test the amount and type of impurity present in any target sample to be used in any experiment of atomic physics/ nuclear physics or of material science. The detection of these impurities before conduction of any experiment is essential as the presence of impurity in target sample may hamper the results of the experiments. Thus, although being a traditional concept the use of Rutherford backscattering spectroscopy still prevails. One requires a target material to learn the working principle of Rutherford backscattering spectroscopy. INTER UNIVERSITY ACCELERATOR CENTER (IUAC) provides the facility for fabrication of the target and its analysis. This paper includes the fabrication of gold target of thickness 300mm and its analysis using Rutherford backscattering spectroscopy.

Key words: Rutherford Back Scattering, Electron Vapor Deposition

I. TARGET FABRICATION

The technique for target preparation is chosen depending on the thickness and the properties of the target material. If the target consists of only one isotope or if the reaction is specific for the element independent of the isotopic composition, then the experimentalist needs to know its thickness or must have a thickness-calibrated target for comparison.

A. Experimental Setup

The high vacuum chamber in the target laboratory of IUAC is used for fabrication of carbon foils as well as foils of other materials. It is equipped with a diffusion pump having a pumping speed of 1000 l/s backed by a direct driven rotary pump. This system can provide a vacuum of the order of 10-6 Torr. In this evaporator, the target material can be evaporated by resistive heating as well as by the use of a 2kW electron gun. The former is used for the material having low melting points, whereas the latter is used for target materials having high melting points. In the electron gun method, the target material is kept in a water cooled copper crucible. The evaporator is also equipped with a quartz crystal thickness monitor which enables to monitor the rate as well as the thickness of material deposited. The system is well equipped with a manually operated shutter for controlling the deposition as per the target thickness requirement.
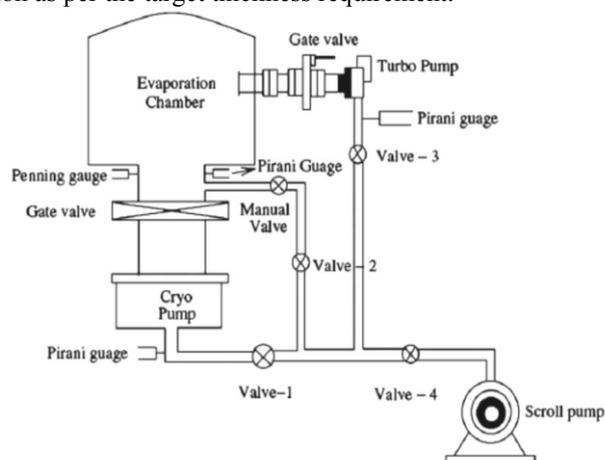

Fig. 1: Schematic diagram of UHV chamber

The Ultra High Vacuum (UHV) evaporator, equipped with a scroll pump, a turbo pump and a cryo pump, was used to prepare the gold targets on carbon backing. In this chamber, a vacuum of the order 10-8-10-9 Torr can be easily achieved. This system has been provided with a 6kW electron gun and with a four pocket copper crucible.

B. Basic steps of Target Fabrication of Gold (having a thickness of 300 nm):

- Deposition of barium chloride, which acts a releasing agent on a glass slide whose melting point, is 962^0C which is less than 1000^0C, so we use the method of thermal evaporation for it.
- Deposition of carbon backing on the BaCl2 coated glass slides for thin targets provides them with support. Melting point of carbon is more than 1000 ^{0}C (3550^0C) so we use the method of electron gun to deposit it on glass slides.
- Annealing with argon gas to increase the strength of carbon backings.
- The carbon coated glass slides are then placed in a chamber on a stand which is at a certain height from the crucible and sample to be deposited on it is put in the crucible/boat. The electron vapor deposition method is then again followed to get the material (here gold) deposited on the glass slides. The targets can be floated on water after being scratched into square shapes with the help of a sharp blade. These are then lifted up on target holders.
- *Alternatively*
- The deposited carbon on the glass slides is first scratched with the help of a sharp blade so as to cut the carbon deposited into square shapes. Slides are then made to slowly immerse in a water bath at an angle whereby carbon floats on water bath. A target holder is then used to lift it up.
- The target holder is then placed in a chamber on a stand which is at certain height from the crucible and sample to be deposited on it is put in the crucible/boat. Electron vapor deposition method is then again followed to get the material deposited on the holder containing carbon backings.
- The thickness of the material being deposited is measured during deposition by a quartz crystal monitor.

C. Preparation of Carbon Foils:

Carbon foils were made in the high vacuum chamber. The parting material used in the carbon foil fabrication was $BaCl_2$. A pellet of barium chloride was made using a hydraulic pellet press. Cleaned glass slides were placed at a distance of 18cm from the material in the crucible. First, barium chloride of 100nm thickness was deposited in a high vacuum chamber at 10^{-6} Torr pressure by resistive heating technique. Later carbon was deposited on it using the electron gun without disturbing the vacuum. After deposition, chamber was left to cool down for 3-4 hrs. Carbon foils of varying thicknesses were produced by this method ($10\mu g/cm^2$ and $15\mu g/cm^2$). These slides were then annealed for one hour using Argon gas. Carbon films were then floated in warm water, taken on target holders and then transferred to UHV chamber
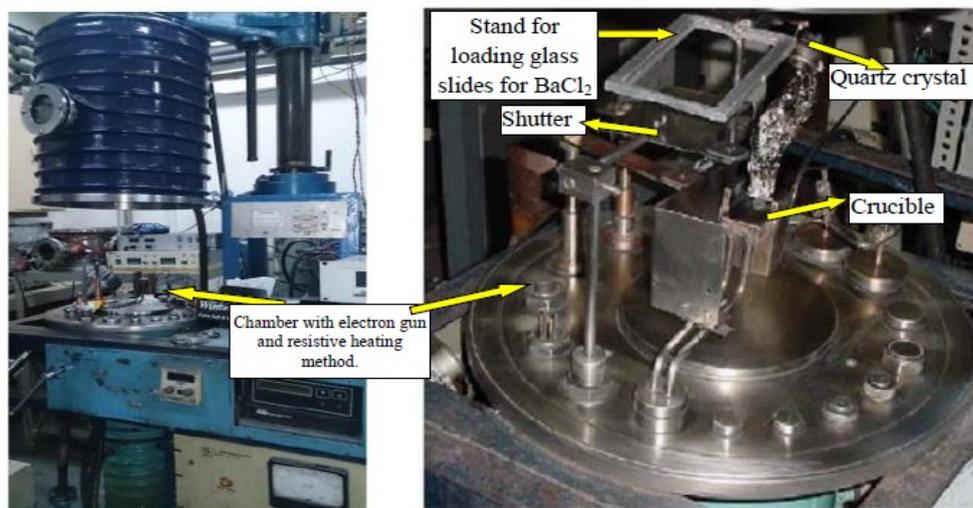

Fig. 2: High vacuum chamber for target deposition. Fig. 3: View inside the chamber with electron gun.

The thickness of the targets was monitored by a calibrated quartz crystal during the deposition process. The deposition rate in this thermal evaporation process at a distance of 20cm from the evaporation source was found to be about ~0.02µg cm-2 s-1 as monitored by an Edwards FTM-5 thickness monitor. For the same target two different thicknesses could be evaporated simultaneously by keeping the carbon backings at two different heights from the electron gun. The height was calculated on the basis of the thickness required and the appropriate tooling factor was provided to the thickness monitor control.

D. Fabrication of Gold Target:

Gold deposition was done by electron beam deposition in UHV chamber at a vacuum of the order of 10-8 -10-9 Torr. Thickness of material deposited was measured and controlled using a quartz crystal monitor. The material i.e. gold was kept in the crucible in UHV chamber and a small amount of current was passed through the electron gun. Later on, the current was increased slowly to 50mA for a few minutes. After a 300 nm target was evaporated on the carbon backing, its thickness was also measured using different methods. Figure 4 shows the Au targets deposited on carbon backings at IUAC. Figure 5 shows a glass slide on which Au target is deposited over a thin carbon backing.
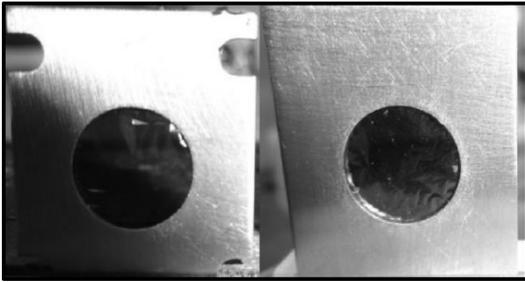
Fig. 4: Au targets with carbon backing prepared at IUAC   Fig. 5: Au target with carbon backing deposited on a glass slide

E.   Conversion of Thickness of Gold Target from Nanometer to Microgram/cm^2

Density of gold = 19.3 g/cm^3
Thickness of gold target required = 300nm
Volume = 300 × 10^{-7}× 1×1
= 3 ×10^{-7+2}
= 3× 10^{-5} cm^3
Mass of gold = density × volume
=19.3× 3 ×10^{-5}
=57.9× 10^{-5}g
For microgram/cm2
Thickness = (5.79 ×10^{-5}) / 10^{-6}
= 579μg/cm^2

Thus a target of gold having a thickness equal to 300nm was prepared in target lab which was later used as a target material for Rutherford backscattering spectroscopy. The thickness of gold target was measured with the help of a quartz crystal present in the target evaporation chamber. The thickness of target sample was found to be ~579μg/cm^2.

F.   Thickness and Uniformity Measurements:

1)   By a thin film monitoring device (quartz crystal):

Quartz crystal monitors are possibly the most versatile thin film monitoring devices. The resonant frequency of the exposed crystal decreases as the mass of the evaporated deposit builds up on it, the change in frequency being an accurate measure of the film thickness. The change in frequency of the crystal is directly proportional to the mass of the element deposited hence the instrument is calibrated for one material only. The relationship of the thickness (μg/cm2) and the frequency of a quartz crystal vibrating in its thickness shear mode is well known. Numerical values yield;

$$\Delta m = 4.417 \times 10^{11} \left(f_f^{-1} - f_q^{-1} \right) \quad [\mu g \, / \, cm^2]$$

Where f_q is the resonant frequency before deposition and f_f is the resonant frequency after the end of deposition. Both frequencies (f) are gauged in Hertz. The above equation is valid for values of acoustic impedance (Z) equal to 1 and for foil thickness smaller than 1 mg/cm^2 because for such thickness the deviation due to necessary Z correction is negligible. Quartz crystals used for these measurements are natural or synthetic single crystals of very pure SiO2. That is why the solid-state constants are very well reproduced from all these quartz crystal sensors. The best accuracy of a target thickness can be obtained when the target material is deposited directly on the quartz, which then acts as a target backing. Mostly quartz sensors are only used as a thickness monitor, for the present study the quartz sensor was placed at the same height and next to the carbon backings used for gold target deposition. The thickness ratio was calculated with the tooling factor and typical errors were ~10 to 20%.

a)   Errors in Thickness Determination:

The most serious problem affecting the accuracy of quartz crystal monitors for thickness determination and the most difficult to eliminate is the frequency shift due to variations in the crystal temperature unfortunately, the measured thickness is falsified by a thin water layer on both sides of the quartz. Depending on how hygroscopic the surface of the quartz is, how high the temperature and the relative humidity are at the moment of measurement; a water layer of 0.2 to 1μg/cm^2 can be detected on each side of the quartz. It is so as both faces of the quartz are sensitive to water deposition. Even in a vacuum of 10^{-6} Pa range, a water layer of about 0.2 μg/cm^2 always remains bound to the surface. In order to avoid this problem the target materials are evaporated from a water-cooled copper crucible by means of an electron gun with a large source-to-substrate distance. It has been observed that such a precaution produces targets with good homogeneity. Apart from this precaution the quartz crystals were cleaned before and after each deposition for an accurate thickness measurement.

Maier-Komor[1] have demonstrated and concluded that a quartz crystal thickness sensor can give absolute thickness accuracy in units of □g/cm2 although precautions against systematical errors must be taken. It is necessary, however, to use other or additional measuring devices to estimate these errors. The same systematical errors are unavoidable when thickness determination is done by the weighing procedure, with the disadvantage that these errors cannot be evaluated so easily.

In order to obtain an accurate value, the thickness of the targets was further verified by the transmission technique using α-particles obtained from a ^{241}Am source and the Rutherford backscattering (RBS) technique.
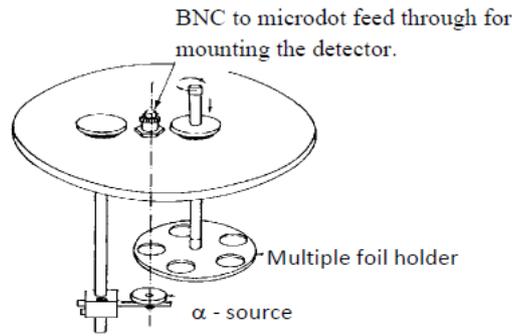
Fig. 6: Set up for measurement of thickness of the foils by alpha particle energy loss method.

2) Alpha Particle Method:

This method utilizes the change in energy of charged particles as they pass through the target foils for measuring both the target thickness and uniformity. It is readily adaptable to those materials whose stopping power is known and whose thickness does not exceed the range of the chosen charged particles. The accuracy of this technique is limited by the accuracy of the stopping power data available. The stopping power values used have been calculated using the TRIM91 [2] code. A vacuum chamber with a rotatable multiple foil holder and source holder has been fabricated at IUAC as shown in Figure 6 to measure the thickness of the foils by alpha particle energy loss method. With this setup the thickness of four foils at a time can be measured without breaking the vacuum inside the chamber. A 10µCi alpha source is collimated by a 1mm aperture and the particle (a surface barrier) detector used has a collimator of 2mm aperture. Alpha particles from the source pass through the aperture to impinge on the target foil. The energy of the attenuated alpha beam is determined by observing the alpha energy shift in a calibrated multi-channel analyzer system. Using the proper stopping power data (defined as the amount of energy lost by the incident particle per cm of target thickness), the target thickness can be determined. When the foil position is varied, the change in energy loss measures the uniformity over a target surface. It has been observed that the thickness variation over a foil of 10mm diameter (made by electron gun bombardment at a distance of 160mm from the source) is ~2.8%. The uncertainties in the counting statistics, surface barrier detector (SBD) solid angle, ion energy, stopping power values and non-uniformity of the elemental layer have been estimated to contribute to the total uncertainty of about 5% in the target thickness

Avasthi *et al.* [3] have found a <12% thickness non-uniformity of the foils made by electron-gun evaporation with the flat geometry of the substrate holding arrangement. They further found that foils made by the electron-gun technique are sturdier as confirmed by the test of foil strength by differential pressure and that they can withstand higher electric fields viz. a 8 to 10µgcm^{-2} foil does not break at a field strength of 1650 Vmm^{-1}.

II. RUTHERFORD BACK SCATTERING SPECTROMETRY

A. Rutherford Scattering

Below the coulomb barrier, the scattering of charge particle are described by the well-known classical Rutherford formula given as:

$$\left(\frac{d\sigma}{d\Omega}\right)_{CM} = \left[\frac{Z_1 Z_2 e^2}{4E_{CM}\sin^2(\theta_{CM}/2)}\right]^2$$

A plot of dσ/dΩ vs. the scattering angle shows that the cross section drops rapidly with a steep slope at forward angles to comparative very low values at backward angles. The formula also shows that near 180° the scattering cross section does not change much with scattering angle. However, at forward angles even a change of 0.5° introduces a change of ~15-20% in the cross section values. The former fact enables one to use the average acceptance angle of the particle detector and still obtain an accurate value for the calculated cross sections near 180°.

Four basic physical concepts of charged particle spectroscopy form the basis of Rutherford backscattering spectrometry (RBS). The kinematic factor (K) leads to the ability for mass analysis. The scattering cross-section provides RBS with a quantitative analysis capability. The stopping cross-section results in the capability for depth analysis and the energy straggling sets limits on the mass and depth resolution.

The ability of the backscattering spectrometry to provide quantitative information on the number of atoms present per unit area of the sample depends on the knowledge of the total number of particles incident on the sample, total number of detected particles and the average scattering cross section σ of the elements is known accurately at backward angles only as described above.

In RBS, charged particles of known mass M1 and known energy Eo are directed at the target of unknown mass M2. By measuring the energy of particles scattered at an angle θ , the unknown mass M2 can be found out. The largest change in K for a given change ΔM2 occurs when θ = 180° ΔM$_2$ being given by

$$\Delta M_2 = \frac{\Delta E}{E_0}\frac{(M_1+M_2)^3}{4M_1(M_2-M_1)}$$

In the vicinity of θ = 180° i.e. $\theta = \pi - \delta$ where δ measures the deviation of θ from π in units of arc and M2 >> M1, the change in energy of the projectile after the collision is given by

$$\Delta E = E_0 \left(4 - \delta^2\right)\left(M_1/M_2^2\right)\Delta M_2$$

Since every practical detection system has a finite resolution, therefore the distinction between two masses is lost if Δ E falls below this limit. To obtain good mass resolution, it is therefore desirable that the coefficient of Δ M2 is as large as possible. To accomplish this, the measurements are done at scattering angles of approximately 180∘ . At the same time either the incident energy Eo is increased or a projectile of large mass M1 is used. However, M2 masses smaller than M1 do not produce any backscattering signal.

The magnitude of the Rutherford cross-section [4] is dominated by the term $\left(Z_1 Z_2/E\right)^2$. Hence RBS has got higher sensitivity towards heavy elements. The cross-section for scattering, which is inversely proportional to the square of the projectile energy, can be rewritten as

$$\sigma \ (\theta) = \frac{(d/4)^2}{\sin^4 \theta/2}$$

where d is the distance of closest approach and is given by

$$d = Z_1 Z_2 e^2/E$$

If the distance of closest approach for a particular projectile target system is less than the K shell radius of the target, then the use of an unscreened Coulomb potential for the calculation of cross-section is justified. The requirement for 'd' less than the K-shell radius sets a lower limit on the energy analysis of the beam and requires that

$$E > Z_1 Z_2^2 e^2/a_0$$

Deviations of the differential scattering cross-section from the Rutherford formula do exist. At larger impact parameters found in small-angle scattering of MeV He+ ions or in low-energy heavy ion collisions, the incident particle does not completely penetrate through the electron shells of the target atoms and hence the innermost electrons screen the charge of the atom. In these situations the electrostatic interaction does not take place between bare nuclei as Rutherford formula assumes.

In RBS analysis of solids, the influence of screening can be included to first order, by using a screened Coulomb cross-section [5] σSC obtained by multiplying the scattering cross-section σ (θ) by a correction factor F

$$\sigma_{sc} = \sigma \ (\theta) \ F$$

where

$$F = \left(1 - 0.049 \, Z_1 Z_2^{4/3}/E\right)$$

and E is given in keV. Consequently, for analysis, the screening correction can be neglected for most target elements. At lower incident energies or with heavier incident ions, screening effects may be important. At MeV energies of the low Z projectiles, there is practically no charge transfer to the electron clouds of the target and the Coulomb interaction of the nuclei is valid. So it is immaterial whether the charge state of the incident projectile is one or two, for example He+ or He++.

For sufficiently high ion energies and small impact parameter values, there can be departures from Rutherford scattering cross-section due to the interaction of the incident particle with the nucleus of the target atom. Deviations from Rutherford scattering due to nuclear interactions will become important when the distance of closest approach of the projectile-nucleus system becomes comparable to R, the nuclear radius. For such a case the energy is given by

$$E = \frac{Z_1 Z_2 e^2}{R_0 A^{1/3}}$$

where A is the mass number and Ro ~1.4 X 10-13 cm. For 4He ions incident on Si, this energy is about 9.5 MeV, and 41 MeV for Li ions incident on Au. Consequently, nuclear reactions and strong deviations from Rutherford scattering do not play a significant role in backscattering analyses at energies of a few MeV.

An energetic particle through a solid loses energy through interactions with electrons and nuclei of the target atoms. In the total stopping cross-section (□) for MeV energy, low Z projectiles used in RBS, the nuclear stopping is negligible except at the very lowest energies (i.e., at the deepest penetration of the projectile beam in the target).

The rate dE/dx at which a particle loses energy is typically 10 - 100 eV/A^0 for ^{4}He and it depends on the energy E, of the projectile. The energy E of a particle at a depth x will be given by

$$E = E_0 - \int_0^x \frac{dE}{dx} \, dx$$

In RBS, our attention is confined to particles that travel very small distances in surface layers of the target. Under these circumstances the rate of energy loss can be considered to be a constant equal to its value at the surface, $(dE/dx) \big|_{E_0}$ i.e., its value at the energy E$_o$ of the incident projectile. The above equation can then be integrated to give

$$E = E_0 - \left(\frac{dE}{dx}\right)\bigg|_{E_0} x$$

This approximation is known as the *surface energy approximation* [4].

To a simple approximation, the process by which a particle loses energy when it moves swiftly through a medium consists of a random sequence of independent encounters between two particles; the moving projectile and an electron attached to a target atom, or the projectile and a target nucleus. To the extent that this picture is correct, the situation

presented by a target that contains more than one element differs only with respect to the type of atoms the projectile encounters. The energy lost to the electrons or to the atomic core in each encounter should be the same at a given projectile velocity, regardless of the further surrounding of the target atoms, since the interaction is considered to take place with only one atom at a time. In essence this is the idea contained in the principle of additivity of stopping cross sections.

B. Rutherford Back Scattering

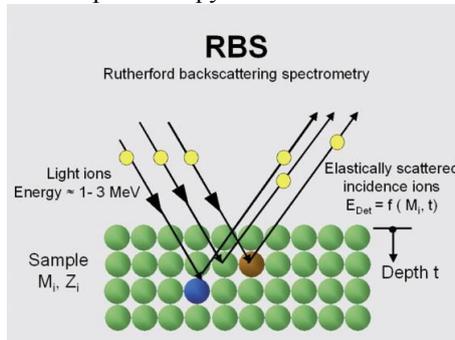Figure 7 shows a schematic diagram of the RBS spectroscopy

Fig. 7: Rutherford Backscattering Spectroscopy (Source: Google images)

C. PARAS Accelerator Facility at IUAC:-

Pelletron Accelerator RBS-AMS System (PARAS) facility has been installed at IUAC which consists of a Rutherford Backscattering Spectrometry (RBS) facility with 1.7 Million Volt Pelletron accelerator. The facility is equipped with:

- Alphatross ion source for producing negatively charged He and H ions.
- 1.7MV 5SDH-2 Pelletron accelerator
- A four axis goniometer (model name RBS-400)

The number and energy of ions backscattered after colliding with atoms of the sample are measured with a surface barrier detector. This allows the determination of atomic mass and elemental concentration as a function of depth below the surface. A photograph of the RBS facility and a schematic diagram of the same is given in Figure 8 and 9 respectively
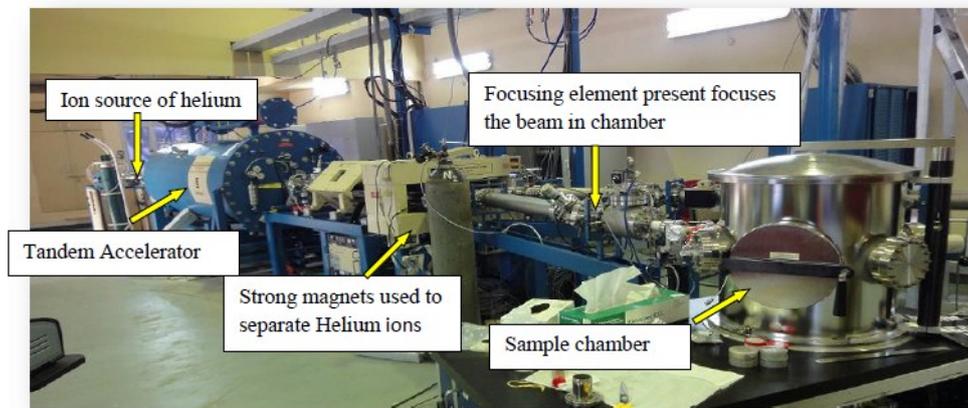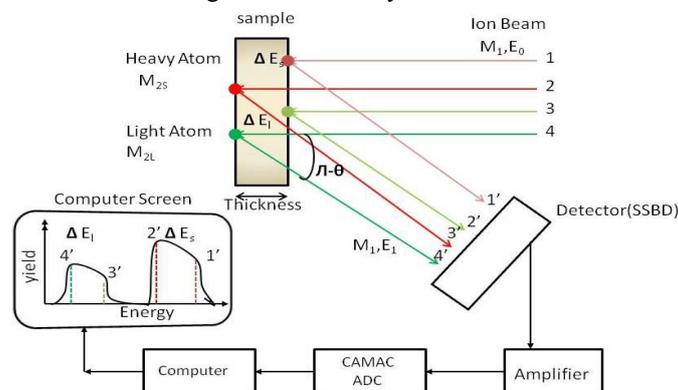

Fig. 8: RBS Facility AT IUAC

Fig. 9: Schematic diagram of RBS facility at IUAC [http://www.iuac.res.in/accel/paras/index.html]

D. Components of PARAS

1) Ion source of helium: Helium He+ or He++ ion is used as an ion source for single ended accelerator with high voltage. Color of helium is aqua green.
2) Duoplasmatron starts with low voltage arc burning between cathode and anode.
3) A typical source produces 1 mA of He+.

4) Tandem accelerator requires negative helium ions but Helium is the most inert gas so it does not tend to lose or gain electrons.
5) Thus Helium ions are needed to convert He+ into He-. Rubidium Chamber is used for this purpose.

Rubidium chamber used to convert He$^+$ to He$^-$

A tube injecting negative Helium ions into accelerator

6) 1 mA of He+ leads to 1µA of He-.
7) The negative ions are injected into Tandem accelerator at 20-30 keV.
8) A Pelletron is a tandem accelerator and it has a mechanical system made up of chains of pellets which contains short conductive tubes connected by insulating material which is used to build up high voltages on Pelletron terminal.
9) Accelerator system is enclosed by a pressure vessel which is filled with SF6 gas, is a highly insulating gas.
10) Two optical components are usually placed between accelerator and chamber.
11) A magnetic field separates He-, He and He+.
12) Focusing elements: A quadrupole lens focuses the beam into chamber and on the target sample.
13) Sample chamber: The sample chamber (Figure 10) consists of target or the target sample on which implantation has to be done. The ion beam strikes the target and gets back scattered from it and detected by surface barrier detectors present in the sample chamber.
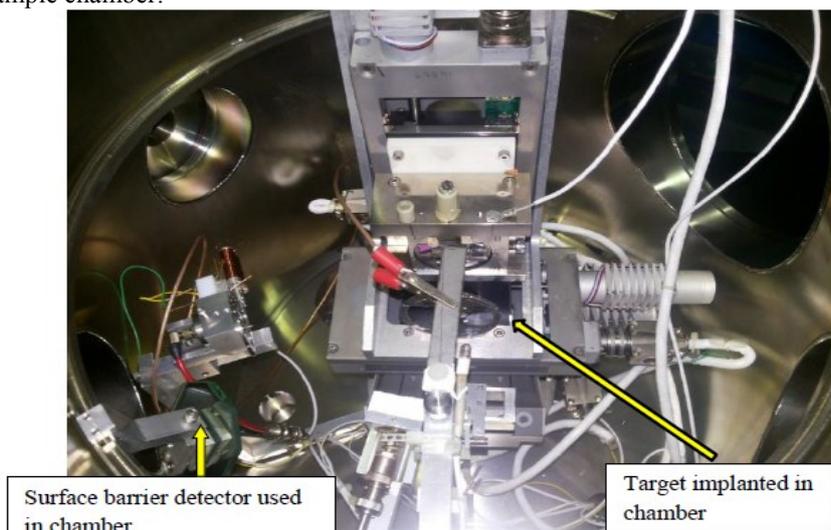
Surface barrier detector used in chamber

Target implanted in chamber

Fig. 10: A view of the inside of the sample chamber

E. Detector used in the experiment

1) Semiconductor detectors
These are devices that are used to record the charged particles or photons which are incident on them. These detectors have a wide range of applications such as in gamma and x-ray spectroscopy and are often used as particle detectors. Apart from energy resolution, the other factors that make semiconductor detectors better than others are its compact size, quite fast timing characteristics and the thickness that can be changed according to the desired experiment.

The radiation incidents on a semiconductor detector are detected by the determination of charged particles collected in detector that is set between two electrodes. The radiation ionized generates holes and free electrons. As the electron hole pair depends linearly on the energy of radiation. Thus the same number of holes is produced in valence band equivalent to the electrons that travel from valence band to conduction band. The electrons and holes now move towards the electrode due to application of electric field and leads to the formation of pulse, which gets determined by circuit mechanism. In order to calculate the intensity of incident beam, the number of electron hole pairs should be known. Since the energy needed to produce an electron hole pair does not depend on the energy of incident beam. The resolution of energy is quite high in a semiconductor detector; also the variation in height of pulse is low.

They are essentially reverse biased junction diodes. They are of two types: Diffused junction detector and Surface barrier detector.

2) Surface Barrier Detector:

These detectors are usually made of n-type silicon. Recently high resistivity p- type silicon has been used to produce thicker surface barrier detectors. Surface Barrier Detector is a n-type silicon wafer diode on which a very thin evaporated gold contact layer is etched. The gold evaporation forms the front rectifying contact of the diode and the rear ohmic contact is made of aluminium.

These detectors have very thin dead layer at the window (~0.1μm). As a result there is very small energy loss for the incoming radiation at the window which is convenient for relatively low energy alpha particle studies. The detectors are however less rugged and must be handled with great care. Basically, it is a semiconductor detector made up of silicon and doped with impurities in order to form a p − n junction. To make depletion region, reverse bias voltage is employed. For operating as a detector, the range of particles should be less than the depletion range. As the particles get into the detector, eventually its energy is lost due to the production of electron hole pairs. This electron hole pair is produced in the depletion region. For silicon the energy needed to form an electron hole pair is about 3 eV. Now, due to the electric field the holes and electrons are deflected towards the opposite side, thus the pulse obtained creates signal, detected by the detector.

The surface barrier detector is mostly preferred if the resolution of the detector is small which leads to better quality of the detector. The Resolution of such detector is inversely proportional to square root of N, where N is the number of pairs produced.

The energy of the back scattered particle peak provides information regarding the elements present as impurities in the target. Depending on the energy resolution of the SBD, impurities of different masses show up as separate peaks in the RBS spectrum, the intensity of the peak depending on the concentration of the impurity.

F. Thickness by RBS technique:

The RBS technique analyzes the Coulomb interaction between a projectile of charge Z1e and a target nucleus of charge Z2e. The energy and scattering angle of the scattered particle provide information on the thickness, the nature of constituents and the profile of the target. The measured quantities in this technique are the scattering angle Θand the energy E of the detected particle. Good energy resolution is an essential quantity for the accuracy of the analysis. Factors controlling a good energy resolution such as the electronics used for data acquisition and the detector type used have been discussed in the subsequent sections. The most important quantity determined in RBS is the kinematic scattering factor k, defined by the ratio of the energy of the backscattered particle E and the incident energy of the projectile E0:

$$k = \frac{E}{E_0} = \left(\frac{\sqrt{(M_2^2 - M_1^2 \sin^2\theta)} + M_1 \cos\theta}{M_1 + M_2} \right)^2$$

Here M1and M2 are the masses of the projectile and the target, respectively. The knowledge of the mass and energy of the projectile and the measurement of the energy E and the angleθ of the backscattered particle allow the identification of the elementary constituents of the sample. Since the amount of backscattered particles from any given element is proportional to its concentration, RBS can be used to quantitatively investigate the depth profile of individual elements in the sample.

The thickness of the foil under consideration is deduced from the width of the RBS spectra using the energy loss data (dE/dx) of the projectile ions in the foil material i.e. by determining the energy of the backscattered particles E1 and E2 at both edges of the sample. The high-energy edge reflects the front and the low energy edge the back of the sample. Sharply defined spectral edges indicate well-defined surfaces. The thickness measured by RBS is given in areal density (atoms/cm2), i.e. the amount of materials present to scatter the incident projectile ions. Generally a systematic decrease of the target thickness from the center to the edges is found which is due to the evaporation process used to produce the target. In our experiments the diameter of the beam spot on the target was ~3mm and the accuracy of the center focus was ~1mm. Rubehn *et al.*[8] noted that the relative uncertainty of the RBS target thickness measurement is below 1% and thus it provides the necessary accuracy to minimize systematic errors in cross section measurements.
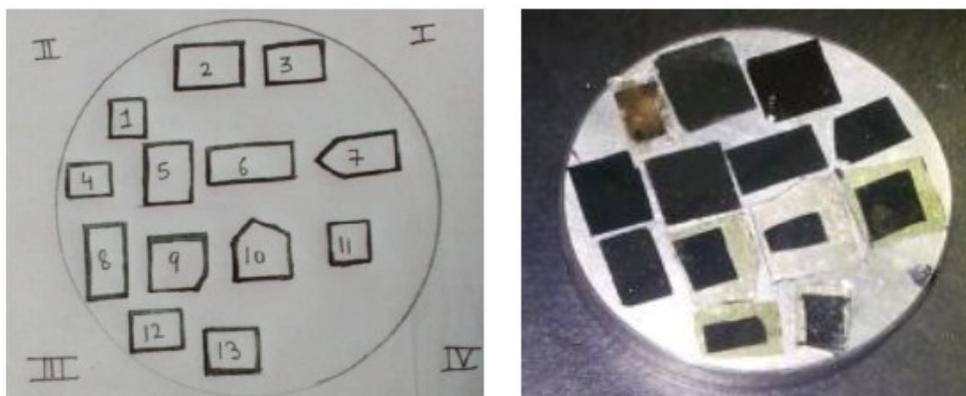
G. Samples used for doing RBS

Fig. 11: Samples used for doing RBS

Figure 11 shows some samples used for RBS spectroscopy in the PARAS facility. The details of the samples are given below in the table

S. No.	Target type	S. No.	Target type
1.	Au / glass (reference sample)	8.	5nm Au-1E16 / Si
2.	10 nm Au- 1E16 / Si	9.	5nm Au / glass
3.	10 nm Au- 1E17 / Si	10.	5nm Au- 1E17 / glass
4.	CdO / Si	11.	10nm Au- 1E16 / glass
5.	10nm Au / Si	12.	10nm Au/glass
6.	5nm Au / Si	13.	5nm Au- 1E16/ glass
7.	5nm Au- 1E17 /Si		

Table 1: list of the target samples shown in Figure 11 as 1 to 13 for positions with corresponding photograph.

Figure 12 shown below depicts a RBS spectrum of gold target on glass recorded by the surface barrier particle detector [9].
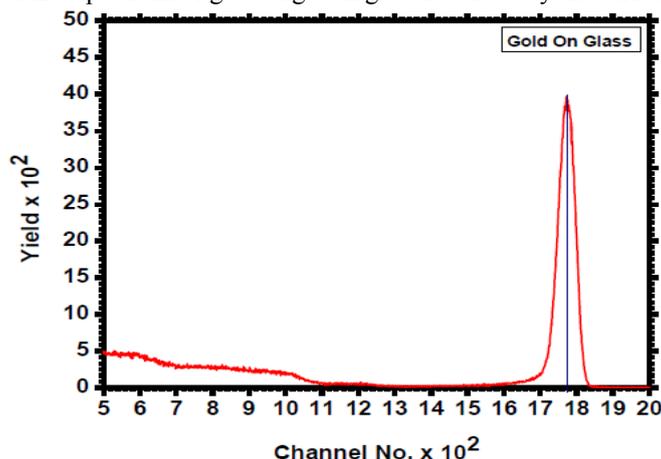

Fig. 12: Au on glass RBS spectrum [9]

III. CONCLUSION

Thus, a target of gold having thickness equal to 300 nm (579μg/cm2) was prepared in the target laboratory which was later used as target material for Rutherford backscattering spectroscopy. The thickness of gold target was calculated from the quartz crystal monitor present in the target deposition chamber. The PARAS facility @IUAC provided an opportunity to learn the concepts of Rutherford backscattering spectroscopy experimentally in addition to theoretical know how as well as the functioning of a charge particle detector e.g. silicon surface barrier detector.

REFERENCES

[1] P. Maier-Komor: Nucl. Instr. and Meth. A **236** (1985) 641.
[2] L. C. Tribedi, S. D. Narvekar, R. G. Pillay, and P.N. Tandon: Pramana **46** (1992) 661.
[3] D.K. Avasthi, Jaipal and S. Gargari: Nucl. Instr. and Meth. A **303** (1991) 43.
[4] W.K. Chu, J.W. Mayer and M.A. Nicolet: Backscattering Spectrometry, (Academic Press,
[5] New York, 1978).
[6] J. L'Ecuyer, J.A. Davies and N. Matsunami: Nucl. Instr. and Meth.**160** (1979) 337.
[7] "Techniques for nuclear and particle physics experiments: a how-to approach" by W.R. Leo.
[8] "Radiation detection and measurement" by Glenn F. Knoll
[9] Th. Rubehn, G.J. Wozniak, L. Phair, L.G. Moretto and K.M. Yu: Nucl. Instr. and Meth. A **387**(1997) 328.
[10] S. Ojha, Inter University accelerator Centre, New Delhi [private communication].