

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Catania

INFN/TC-88/5

1 Febbraio 1988

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Servizio Documentazione
dei Laboratori Nazionali di Frascati

ANGULAR DEPENDENCE ON THE SPUTTERING YIELD MEASURED BY LOW
ENERGY PIXE ANALYSIS

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ABSTRACT

Sputtering yield of Au thin films by 80 keV argon ions bombardment has been measured "in situ" using the PIXE analysis with low energy proton beams (100 keV).

Typically a rising yield is seen, as the angle between surface normal and incoming beam, θ , increases from zero, according the $\sec \theta$ law.

The measured angular dependence on the sputtering yield and the used analysis method have been discussed in detail.

1. - INTRODUCTION

During ion implantation, whenever the collision cascade intersects the surface, atom ejection occurs if the surface atom recoils have an energy excess on the surface binding energy (typically 2-5 eV)⁽¹⁾. This phenomenon is known as sputtering. The sputtering yield, Y , is defined as the number of sputtered atoms per incident ion.

Heavy ions bombardment, in the KeV energy region, produces a sputtering effect due, essentially, to the energy deposition by nuclear collisions. The sputtered material quantity depends by incidence angle, θ , respect to the sample surface normal. This dependence is theoretically predicted by $(\cos \theta)^{-1}$ and can be ascribed to the normal penetration of incident ions that becomes progressively less for large incidence angles^(2,3).

In this work I report on the influence of the bombardment angle on the sputtering of Au thin films by 80 KeV Argon beam. The sputtering yields were measured "in situ" using, successively to the Argon fluence, 100 KeV proton beam induced X-ray emission (PIXE analysis). Typically a rising yield is seen as θ increases from zero, a pronounced maximum appears somewhere in the range above 60° , and there is a sharp fall as θ approaches 90° .

(1) P. Sigmund : Phys. Rev., V.184, n.2, 383, (1969).

(2) H.H. Andersen : Sputtering of multicomponent metals and semiconductors; M. Matic Ed., SPIG, (1980).

(3) H.H. Andersen and H.L. Bay : Sputtering by ion bombardment; R. Behrisch Ed., Springer Verlag, (1982).

No consideration has been made on the channeling effects in the polycrystalline specimens⁽⁴⁾, on the target temperature effect⁽⁵⁾ and on the surface topography⁽⁶⁾.

2. - MATERIALS AND METHODS

Au thin films were prepared by vacuum deposition on to SiO₂/Si substrate. Au thickness was measured using 2.0 MeV helium RBS technique and were selected the thickness of 3×10^{17} atoms/cm².

Target were placed in the scattering chamber of the Ion Implantation Laboratory of the Catania University Physics Department. Rotating target holder was employed to vary the incidence angle with an accuracy within ± 1 degree. A Si(Li) X-ray detector (FWHM=180 eV at 6 KeV) was placed at 90° respect to the incident beam direction and a mylar foil of 6 μ m thickness was placed between the detector and the chamber, as shown in the experimental set up of Fig.1 . Sample-detector distance was 8cm and the solid angle subtended by detector was 15 mst. The pressure in the chamber was 10^{-7} torr. The Au M α lines detection efficiency (2.1 KeV) was 16% . A shielding cup could be biased to suppress or collect charged secondary particles.

(4)M.J. Witcomb : Rad. Eff.,V.27,223,(1976).

(5)J.J.Ph. Elich,H.E. Roosendaal and D. Onerdelinden : Rad. Eff.,V.14,93,(1972).

(6)K.B. Cheney and E.T. Pitkin : J. Appl. Phys.,36,3542,(1965).

Experimental set-up

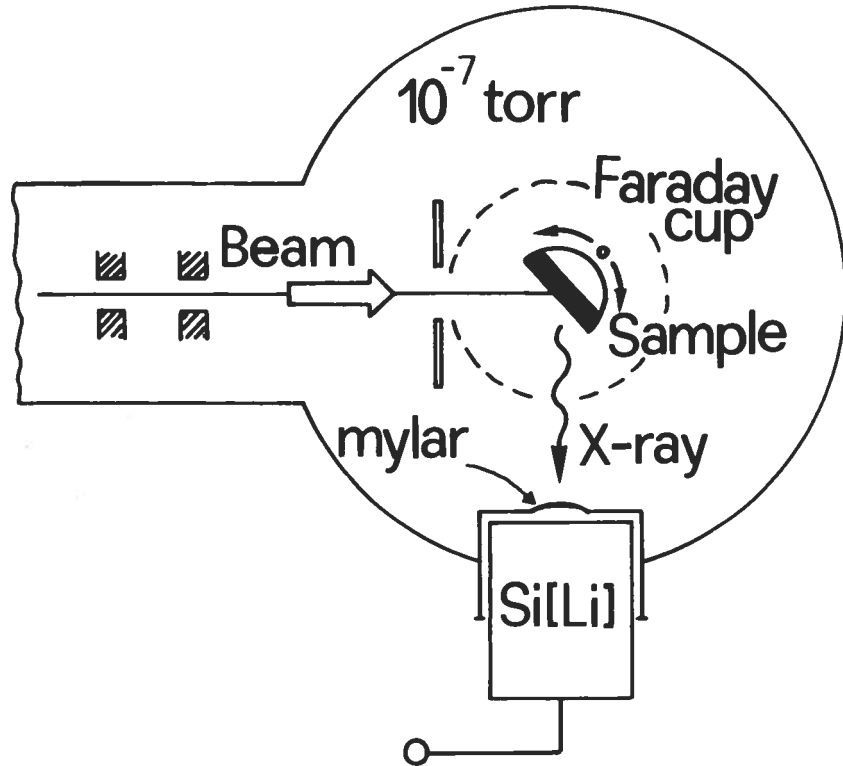


Fig.1 : Experimental set - up .

At first, using an Au thin film as marker, 10^{17} atoms/cm² thickness, and an incidence angle of 45° respect to the surface normal, I have measured the experimental Au M_α lines X-ray production induced by protons beam in the energy range of $50 \div 100$ KeV. Measurements have shown a strong beam energy dependence on the X-ray production cross section, as shows the Fig.2 .

Successively, an as deposited Au film, 3×10^{17} atoms/cm² thickness, has been bombarded using 100 KeV proton beam with a current of 100 nA and a spot of 6 mm^2 (in normal incidence) at different incidence angles. In gold, 100 KeV protons have a stopping power of $3.8 \text{ KeV}/10^{17} \text{ ats/cm}^2$ and a

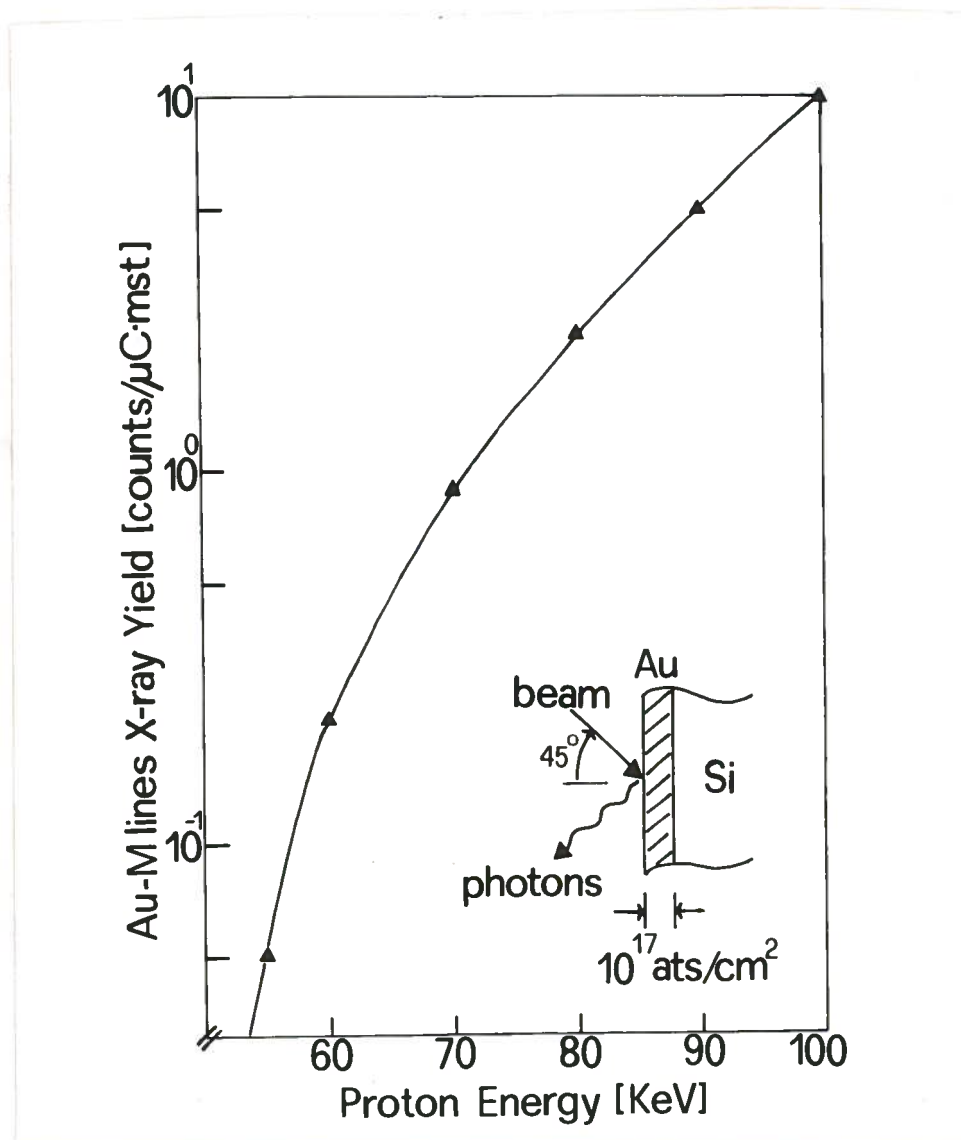


Fig.2 : Experimental Au-M lines X-ray production yield versus proton energy in the range 50-100 KeV.

range of $3000 \text{ \AA}^{(7)}$. When, in normal incidence, 100 KeV protons beam cross the Au film whereas it is totally stopped in glancing conditions. Considering the decrease of the X-ray production along the ion track and supposing the Au sample as bulk and subdivided in steps of 10^{17} atoms/cm² has been possible to calculate the X-ray yield contribution of each step to the total emission.

(7) H.H. Andersen and J.F. Ziegler : Hydrogen stopping power and ranges in all elements, J.F. Ziegler Ed., Plenum Press, 3, (1977).

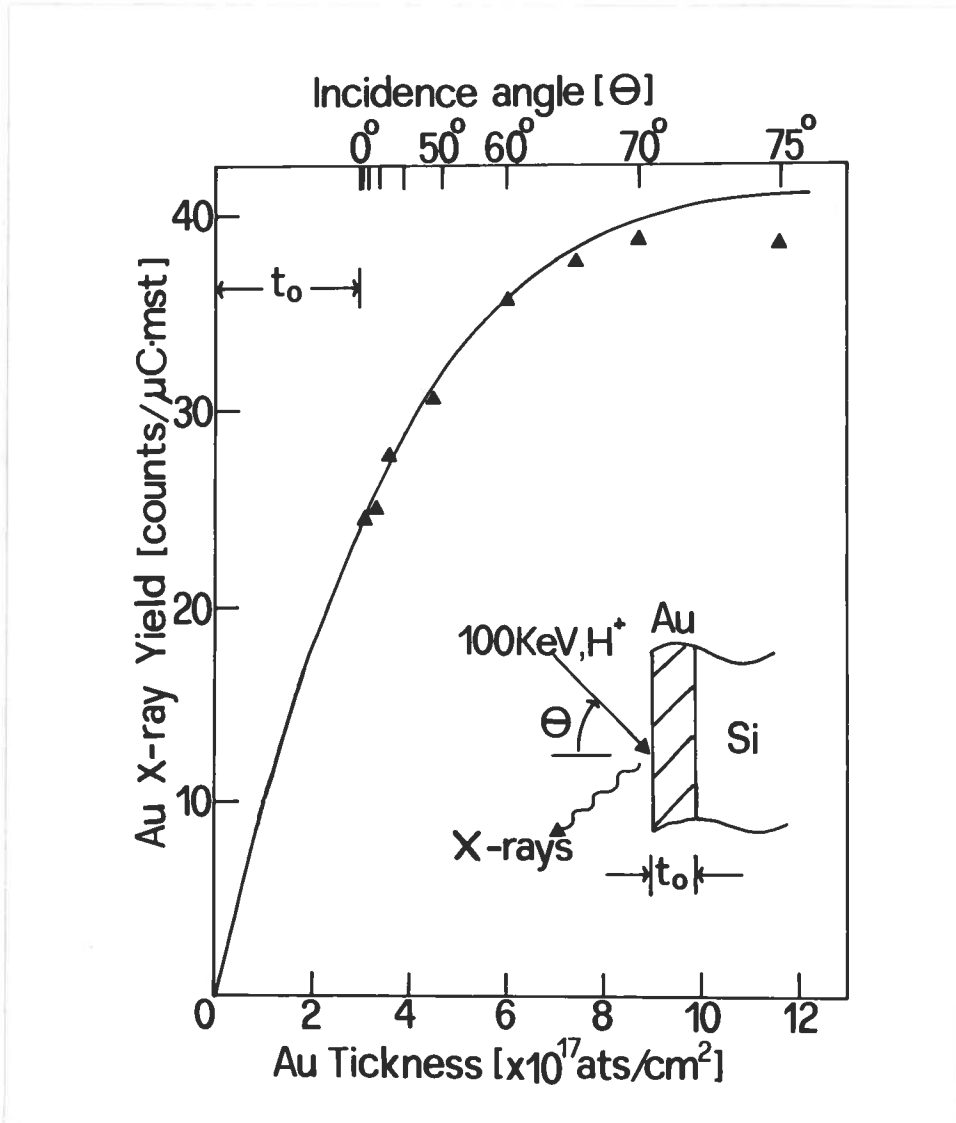


Fig.3 : Theoretical X-ray yield dependence on the Au thickness and experimental measurements on a 3×10^{17} atoms/cm² film tilted at different incidence angles.

Fig.3 shows the calculated X-ray emission yield versus the Au thickness for 100 KeV impinging protons (full line) and the incidence angle dependence on the beam incoming depth, according the simple relation $t_0/\cos\theta$. Starting from $t_0 = 3 \times 10^{17}$ atoms/cm² Au thickness, as deposited film, the figure shows also the experimental measurements on the X-ray emission yield versus the incidence angle θ (triangles).

The X-ray yield-thickness dependence is almost linear for thickness less than 5×10^{17} ats/cm² ($0 < 53^\circ$). For thickness higher than 10^{18} ats/cm² ($\theta > 72^\circ$) the yield is thickness

independent due to the ionization cross section decrease with the depth.

100 KeV protons, as analyser beam, was alternated to 80 KeV Argon ions sputtering. The argon beam projected range in gold is 240 Å⁽⁸⁾.

Argon current were maintained at 100 nA and the given doses were of the order of 10^{16} ions/cm². Argon dose was calculated respect to sample surface projected spot, according the geometrical relationship $S_0/\cos\theta$, where S_0 is the spot in normal incidence (2×3 mm²).

3. - RESULTS

As in a precedent paper⁽⁹⁾, the sputtering yield measurements have been showed plotting the Au M lines X-ray yield decrease versus the argon fluence. Fig.4 reports the experimental measurements on the Au films sputtering yield for three different incidence angles: 15°, 45° and 70°, respectively. The method is self-consistent because the starting Au yields, and successively to the given sputtering dose steps, at different incidence angles, are measured in the same experimental conditions. PIXE analysis, using 100 KeV protons and doses of the order of 10^{15} protons/cm², has been used as Au thickness analyser.

(8)B. Smith : Ion implantation range data for silicon and germanium device technologies, B. Smith Ed., Harwell, (1977).
(9)L. Torrisi : Il Nuovo Cimento, V.7D, n.1, 70, (1986).

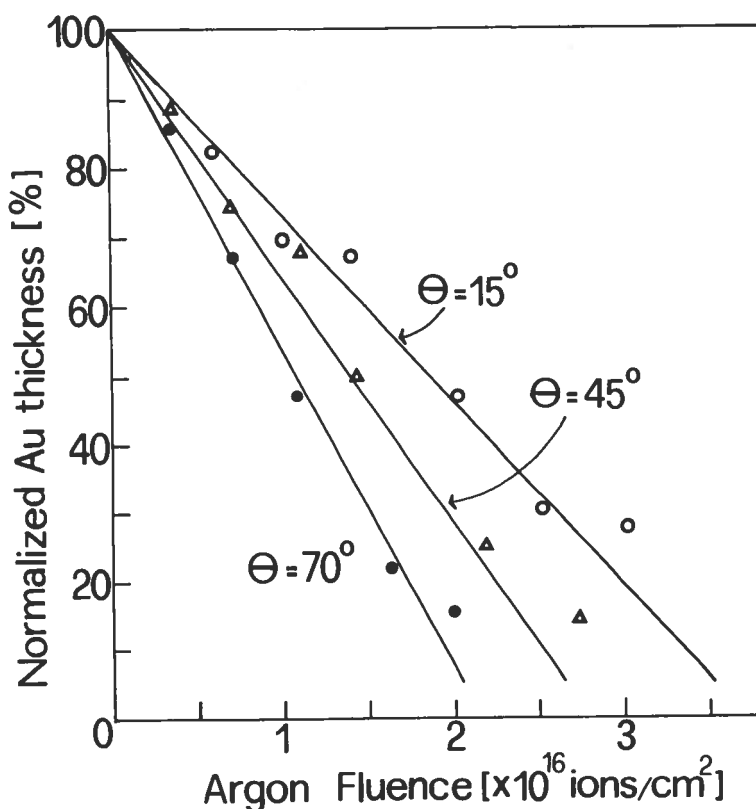


Fig.4 : Erosion measurements of the Au normalized thickness versus 80 KeV argon fluence for three different incidence angles.

Experimental results on erosion of thin gold layers by 80 KeV Ar^+ at room temperature give $Y \approx 10$ ats/ion for $\theta = 15^\circ$, sputtering effect decrease due, probably, to the increase ions scattering from the sample surface.

According Sigmund theory⁽¹⁾, the sputtering yield goes through a maximum at very oblique incidence and approaches zero for $\theta = 90^\circ$. Infact, will be a certain angle, depend on the structure of the surface, at which the repulsive action of the surface atoms is strongly enough to prevent the ions from penetrating into the target.

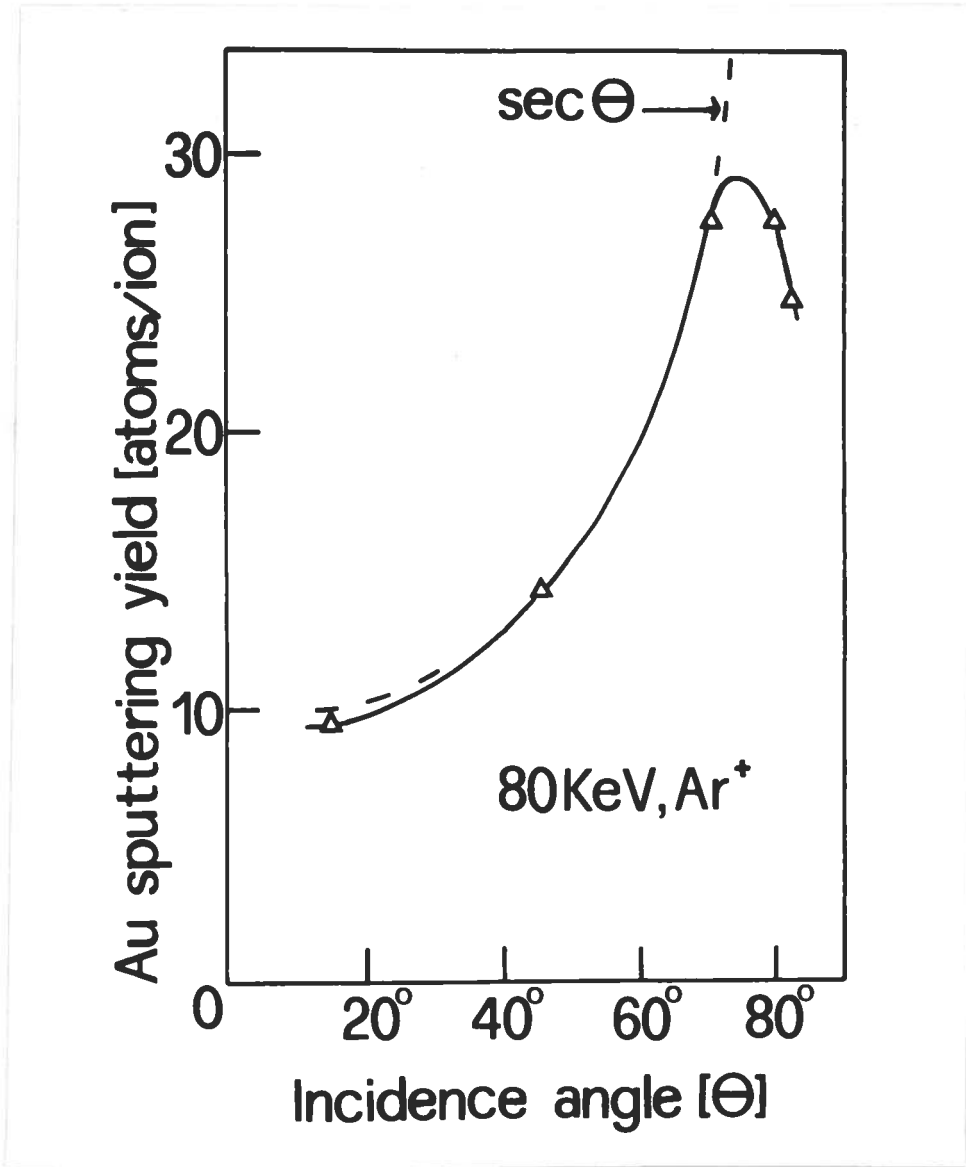


Fig.5 : Experimental incidence angle dependence on the Au sputtering yield by 80 KeV argon beam and comparison with the $\sec \theta$ theoretical trend.

Fig.5 shows a results summary as angular dependence of sputtering yields $Y(\theta)$. The simple law

$$Y(\theta) = Y_0 \sec \theta \quad (1)$$

where Y_0 is the sputtering yield in normal incidence, holds only over a limited range of low θ . A pronounced maximum appears close to 70° and there is a sharp fall as θ approaches 90° . Computed sputtering yields are estimated to be accurate within $\pm 15\%$ based primarily upon the accuracy PIXE analysis.

4. - DISCUSSION AND CONCLUSIONS

The curve of the sputtering yield versus angle of ion incidence depend on $(U_0/E)^{1/2}$ where U_0 is the surface binding energy and E is the ion energy⁽¹⁰⁾.

So the erosion yield increase at large incidence angle can be due to the deposited energy increase at the target surfaces. In all cases literature investigated, the yield increase rapidly for larger angles. Such behaviour is thought to be caused by a rapid increase in the reflection coefficient as the direction of incidence approaches the glancing one.

Sigmund showed that the $\sec \theta$ trend, fitted by experimental results, should be expected only for large M_2/M_1 ratio (target/incident atom masses). For smaller mass ratios, a faster variation with angle should be expected⁽¹⁾. The angle effect plays an important role in the study of the momentum transfer concepts of sputtering and an understanding of this effect should be contribute to a more precise sputtering theory. The above result comments are apply to a model where the atoms in the medium are disposed at random. Experiments with crystals show that orientation of the crystal lattice strongly influences the sputtering yield-incidence angle dependence⁽⁵⁾.

The purpose of this parer has been to present an alternative method, to the Rutherford Backscattering spectroscopy, for to

(10)H. Oechsner : Z. Physik, 261, 37, (1973).

measure "in situ" the sputtering yield in thin films using an implanter at low energy. This can be useful, for example, for to investigate on the sputtering effects at low and high target temperatures and during ion-mixing process.

I hope, in future, of to continue the present study on the angular dependence of the erosion yield changing the beam energy, the incident ions and the temperature and the material of the target.

Acknowledgments

I wish to thank Mr. A. Trovato, of the Ion Implantation Laboratory of the Catania University Physics Department, for his expert technical collaboration during ion implantation experiments.

Riassunto

La resa di sputtering di film sottili di Au, da parte di fasci di ioni Ar^+ da 80 KeV, è stata misurata "in situ" adoperando l'analisi PIXE con un fascio di protoni a bassa energia (100 KeV).

All'aumentare dell'angolo di incidenza θ , formato dalla direzione del fascio incidente con la normale alla superficie del campione, è stato visto un aumento della resa di sputtering in accordo alla legge $\sec \theta$.

La dipendenza angolare della resa di sputtering ed il metodo di analisi adoperato sono stati discussi dettagliatamente.