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CALCULATIONS OF THE SPUTTERING YIELD OF SOME ELEMENTS WHEN BOMBARDED WITH NITROGEN IONS

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Abstract

Expanded calculations of the objective sputtering process were completed(Copper, Zinc, Silver, Cesium, Barium) bombarded with nitrogen ions, the calculations were included changing the input parameters for the energy of nitrogen ions and their incidence angle of the target. The program has employed TRIM to perform these calculations. The sputtering yield is directly dependent on these parameters, as changing the incidence angles of the nitrogen ion beam and its energy lead to a tangible change in the output of the perfusion yield. With regard to the target in terms of the thickness of its bombarded layer by proving the parameters of the ions have a direct effect on the atomization yield. The input parameters of the falling ion beam were changed as well as the target to see how they affect the sputtering yield. We found in this study that the best angles of incidence for these ions are when they are close to the angle of 800 and that the higher the energy of the falling ions, the greater the sputtering yield.

Keywords: Sputtering Yield, TRIM Program, Nitrogen Ions.

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Introduction

One of the important applications of plasma is the process of sputtering to the surfaces of materials when its ions interact with these surfaces. When the ions of the plasma beam hit the target, it loses energy through two mechanisms: the nuclear elastic collision, and the electronic inelastic collision. These ions can, depending on their energy, bounce directly back of the target, they can bounce off the surface after a series of successive collisions, or finally resting in a state, where it is embedded in the target at a certain depth within the target is below the surface of the sample. If the collision is an inelastic collision, the ions will lose a large amount of energy to the target and eventually become electrically neutral. The ions can also expel secondary electrons because of this collision. In addition, occurring inelastic scattering also leads to the production of photons and Plasmon's in metals [1].

As for atoms or ions, the target is to be expelled from their original positions. During this bombardment process, energy and momentum are transferred from falling ions to atoms target. If the kinetic energy is enough to overcome the surface binding energy, the atom will receive sputtering from the surface [2].

Physically, the sputtering yield process is referred to as a coalitional process in which the transfer of kinetic energy and momentum from ions is taken into consideration. It regulates the energy and momentum that transfer a series of energy contributions between a large number of target atoms within target. If enough momentum is transferred to the target atom in the direction of the vertical surface, so that there is enough kinetic energy to overcome the binding energy, the target atoms will be sprayed from the surface [3]. The process of forming a chain of collisions can be described in terms of analytical using the application of statistical transfer theories, or by using computer simulations, which follow the evolution of a chain Collisions from one collision to another. Each of these methods has a similar basis; The assume that approximate correctness binary collision, i.e. projectiles sequentially confront the target atoms [4]. In order to accomplish the sputtering process, we need the plasma for generating a source of ions that will hit and corrode the target. There are two main types of systems used to produce plasma for sputtering, which is incandescent discharge and radio frequency plasma (RF). These ions are usually noble gases, such as argon, neon, or xenon [5], and nitrogen can also be used. Optimum selection of ions; It should be based on the fact that the atomic weights of the ions and the target atoms are close. The simulation program that employs the sputtering process is TRIM. The program name comes from the first letters of the English phrase (Transport of Ions in Matter), and it is one of the most comprehensive programs included in the general program called SRIM. The TRIM program is a Monte Carlo algorithm [6]. In which the TRIM and the resulting returns are followed the deceleration processes of each of them until their energy is below the threshold energy. Thus, detailed calculations can be made of the energy transferred to each of the atoms of the collision target. In addition, since the program is a Monte Carlo algorithm, the program is in its nature a statistical program that uses the Coulomb envelope potential, and it includes an electronic stop operation. In this paper, the TRIM program was used to calculate the atomization yield of some elements by means of nitrogen ions when changing the most important input parameters in the sputtering process, such as the kinetic energy of the storming ions, and their angle of incidence [7].

Theory:

Sputtering yield has a tendency to increase with increasing incident ion mass. At incident ion energies that is less than the threshold energy (Eth) sputtering will not happen, but more than (*Eth*) sputtering yields normally increasing with the increase of occurrence ion energy [8].

A perceptive of sputtering yield demands consideration of the interaction between an ion beam and the target. Sputtering occurs because of a chain of elastic collisions where force is changed from the incident ions to the target atoms contained by a collision cascade area. A surface atom can be expelled like a sputtered particle if it has a part of kinetic energy that is satisfactory to conquer the surface binding energy (SBE) of the objective material [9].

Losses of energy is occurred because of inelastic scattering actions where the electrons of the ion act together with the electrons of the target atoms (electronic ionization ,excitation, electron - electron collisions) [10]. A surface atom can be ejected from the surface. If it receives an energy transfer bigger than the surface binding energy, this kinetic energy transfer ejection method is termed physical sputtering [10]. The definition of the sputtering yield assumes that the number of atoms removed is proportional to the number of fallen particles, while all other factors remain constant. In addition, since the target is a solid material, and the beam of ions is ejected with an angle of incidence θ_0 and energy E_0, this leads to a series of elastic collisions with the target atoms when the electronic excitation of the target is neglected [11].

$$Y = \frac{atoms\ removed}{incident\ particle} \qquad \ldots..(1)$$

One of the target atoms will bounce back after receiving energy from the collision process, and it can cause a bouncing motion to other atoms.

Therefore, a series of coalitions motions of the atoms will be formed around the path of the falling ion. If the direction of movement of some of the atoms that perform the sequential movement is towards the solid surface, and if the kinetic energy is greater than the surface binding energy, then it will be able to overcome the restrictions of the surface and then sputtering will occur.

It is clear that the value of the sputtering yield is proportional to the number of moving atoms sequenced. The energy required for the atoms to move in a successive series is at the expense of energy losses from the falling ion, so the sputtering yield is related to the falling ions.

In general the sputtering process, the energy of the ions is small, so that the effect of the electronic stopping power on the function (x, E, θ)can be neglected and since the collision process is elastic between the nuclei of the atomization process, the collision on the surface of the target will be taken into account, which means that the atoms The feedback must overcome the limitations of the target surface before sputtering. Therefore, the resultant spraying can also be expressed [11].

$$Y(E_0,\theta_0)=\Lambda F_D(0,E_0,\theta_0) \qquad \ldots\ldots\ldots\ldots \quad (2)$$

It is Λ factor related to the target material, and it is only related to the characteristics of the target, such as surface binding energy. Expresses the equation [8]:

$$F_D(0,E_0,\theta_0)=\alpha N S_n(E_0) \qquad \ldots\ldots\ldots\ldots \quad (3)$$

N: is the atomic density of the target.

α: The correction factor, which is a function of the mass ratio between the mass of the bombed target to the mass of the projectile and the initial angle of incidence M_2/M_1

$S_n(E_0)$: is the cross-section of the nuclear stop. Therefore, the atomization yield can be described[11]:

$$(E, \eta) = \Lambda \alpha N S(E_0) \qquad \ldots\ldots\ldots \quad (4)$$

:is a general parameter for energy. In order to accurately calculate the atomization yield, the nuclear stop cross-section can be used, as (E_0) is given by the equation[11]:

$$(E)=\frac{8.462\,Z_1Z_2}{(1+M_2/M_1)(Z_1^{0.23}+Z_2^{0.23})}\,S(\varepsilon)\ [10^{-15}\ \text{eV}\cdot\text{cm}^2] \quad .... (5)$$

Since Z_1 and Z_2 are the atomic numbers for each of the falling particle and the bombarded target material, respectively, and ε is the reduced energy that is given by the equation [11]:

$$\varepsilon=\frac{32.53M_2E}{Z_1Z_2(1+M_2/M_1)(Z_1^{0.23}+Z_2^{0.23})} \quad .... (6)$$

The energy unit of the falling ion E is keV and that (ε) is the limit of the decrease in the nuclear cross section of a bundle of ions with energy $\varepsilon \le 30$, it is described by the equation[11]:

$$S_n(\varepsilon)=\frac{0.5\ln(1+1383\varepsilon)}{\varepsilon+0.0132\varepsilon^{0.21226}+0.19593\varepsilon^{0.5}} \quad .... (7)$$

Results and discussion

1-The sputtering yield depends on the angle of incidence

Table (1), (2), (3), (4) and (5) in the case of taking different angles of incidence starting (0^0-89^0) with the energy value remaining (50Kev) the sputtering yield increases as the angle of incidence increases and the increase begins to become clear at angles greater than 70^0. In all calculations, the number of ions falling on the target was fixed and equal to 1000 ions.

From Figure (1) it is noticeable that the sputtering product increased non-linearly with increasing the angles of incidence on the targets (Cu, Zn, Ag, Cs, Ba) and this appears at large angles .

Table (1) the values of the sputtering yield for a Copper target at different angles of fall between (0^0-89^0)

Angle of Incidence(degree)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
0	0.902	93.44
5	0.932	82.74
10	1.09	97.9
15	1.04	82.41
20	1.16	89.62
25	1.48	70.6
30	1.34	84.47
35	1.49	99.44
40	1.65	82.4
45	1.58	70.71
50	2.33	72.12
55	2.6	57.59
60	3.11	77.51
65	3.75	87.37
70	5.02	81.48
75	6.79	82.62
80	9.91	84.03
85	11.31	85.83
89	7.45	120.95

Table (2) the values of the sputtering yield for a Zinc target at different angles of fall between (0^0-89^0).

Angle of Incidence(degree)	**Sputtering Yield (Atoms/Ion)**	**Sputtering Yield (ev/Atom)**
0	1.70	**17.47**
5	1.84	**27.65**
10	1.58	**13.88**
15	1.89	**24.16**
20	2.11	**42.36**
25	1.94	**40.32**
30	2.04	**35.99**
35	2.2	**50.15**
40	2.66	**34.56**
45	3.16	**36.85**
50	3.41	**41.62**
55	4.26	**50.62**
60	4.84	**42.36**
65	6.39	**46.07**
70	8.97	**48.59**
75	11.51	**41.69**
80	16.11	**50.4**
85	19.51	**54.36**
89	11.98	**72.16**

Table (3) the values of the sputtering yield for a Silver target at different angles of fall between (0^0-89^0).

Angle of Incidence(degree)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
0	0.906	**105.75**
5	0.881	**94.83**
10	0.767	**116.45**
15	1.06	**60.5**
20	1.03	**44.86**
25	1.35	**65.73**
30	1.03	**88.54**
35	1.25	**68.83**
40	1.27	**62.12**
45	1.98	**88.21**
50	1.71	**47.49**
55	2.54	**81.16**
60	2.67	**70.16**
65	3.52	**73.58**
70	4.36	**55.3**
75	5.69	**58.14**
80	8.37	**65.18**
85	8.9	**79.91**
89	5.21	**120.31**

Table (4) the values of the sputtering yield for a Cesium target at different angles of fall between (0^0-89^0).

Angle of Incidence(degree)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
0	0.161	99.37
5	0.154	97.39
10	0.158	116.39
15	0.168	159.09
20	0.142	103.32
25	1.69	132.78
30	0.16	72.91
35	0.271	51.24
40	0.258	54.05
45	0.251	79.36
50	0.359	92.24
55	0.313	97.17
60	0.368	135.69
65	0.449	142.83
70	0.522	119.1
75	0.972	107.26
80	1.27	90
85	2.48	126.36
89	2.43	156.97

Table (5) the values of the sputtering yield for a Barium target at different angles of fall between (0^0-89^0).

Angle of Incidence(degree)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
0	0.259	259.82
5	0.284	77.73
10	0.282	96.69
15	0.227	124.97
20	0.251	194.28
25	0.292	78.23
30	0.278	152.98
35	0.359	150.98
40	0.342	95.09
45	0.412	111.6
50	0.44	91.41
55	0.566	77.46
60	0.587	135.79
65	0.772	153.29
70	0.999	131.77
75	1.43	127.11
80	1.97	133.28
85	3.08	137.77
89	2.58	129.47

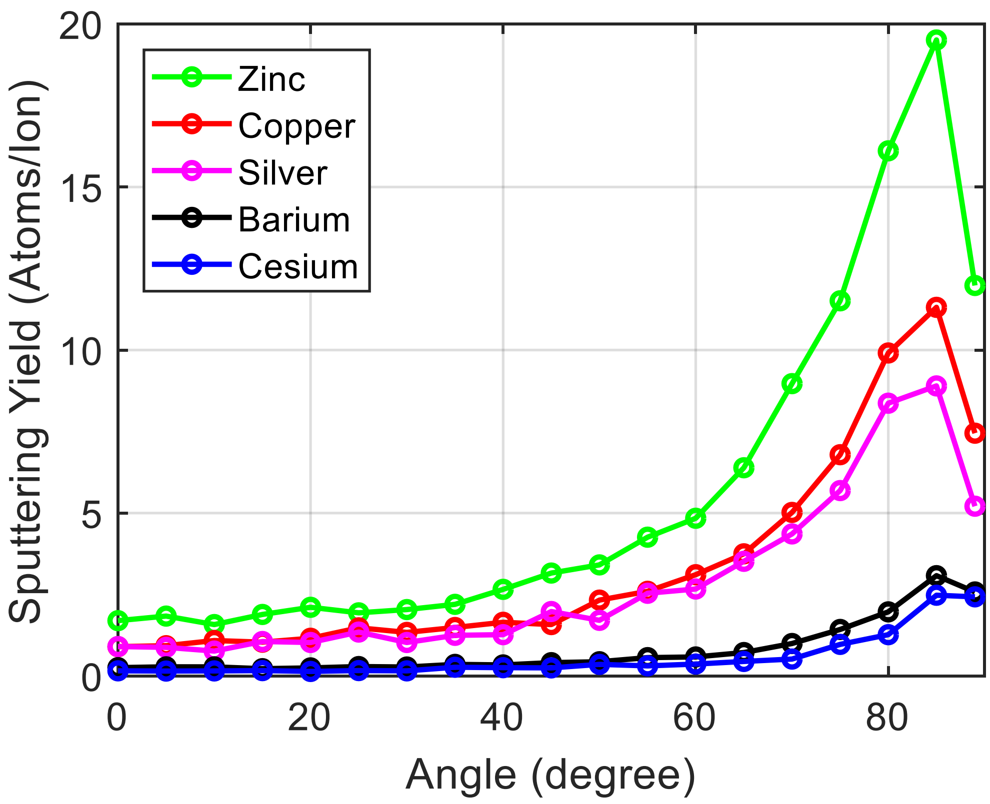

Figure 1: The effect of angles of incidence on the sputtering yield.

(2) The effect of the energy of the falling ions on the sputtering yield:

The tables (6),(7),(8),(9)and(10) shows the values of the sputtering yield at different energies and with a fixed angle of incidence equal to (0^0). The sputtering yield decreases with the increase in the energy of the ion falling on a target of copper, zinc, silver, cesium and barium.

Figure (2) shows that when the energy of the ions falling on a target of (Cu, Zn,Ag, Cs, Ba) increases, the amount of sputtering yield decreases.

Table (6) the values of the sputtering yield for a copper target at different energies.

Energy (Kev)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
50	0.902	**93.44**
100	0.824	**73.16**
150	0.844	**38.17**
200	0.512	**150.10**
250	0.496	**146.84**

Table (7) the values of the sputtering yield for a zinc target at different energies.

Energy (Kev)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
50	1.7	17.47
100	1.25	66.07
150	1.19	46.98
200	0.603	76.71
250	0.579	71.21

Table (8) the values of the sputtering yield for a silver target at different energies.

Energy(Kev)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
50	0.906	105.75
100	0.603	57.43
150	0.504	89.26
200	0.374	37.08
250	0.451	36.38

Table (9) the values of the sputtering yield for a cesium target at different energies.

Energy(K ev)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
50	0.161	**99.37**
100	0.187	**41.68**
150	0.139	**26.38**
200	0.073	**10.45**
250	0.074	**13.74**

Table (10) the values of the sputtering yield for a cesium target at different energies.

Energy(K ev)	Sputtering Yield (Atoms/Ion)	Sputtering Yield (ev/Atom)
50	0.259	259.82
100	0.168	155.31
150	0.193	161.14
200	0.206	99.82
250	0.157	183.12

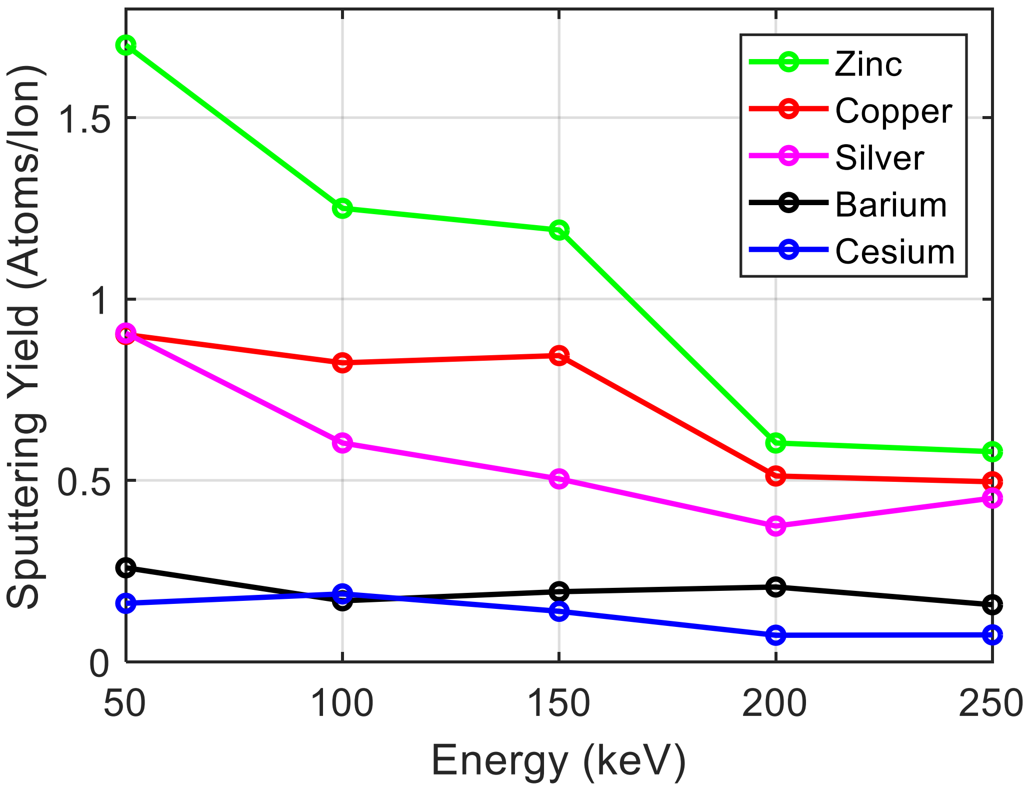

Figure 2: The effect of energies on the sputtering yield.

Conclusions:

The calculations of this research were carried out using the TRIM simulation program to study the sputtering yield of a targetes (Cu, Zn, Ag, Cs, Ba) when bombarded with nitrogen ions. The input parameters of the falling ion beam were changed as well as the target to see how they affect the sputtering yield. We found in this study that the best angles of incidence for these ions are when they are close to the angle of 80^0 and that the higher the energy of the falling ions, the greater the sputtering yield.

References

1. Lucille, A. Giannuzzi and Fred, A. Stevie (2005) Introduction to Focused Ion Beams: Instrumentation, Theory, Techniques, and practice. Springer.
2. Moshfegh,A. Z. (2009) ,Sputtering Deposition: Physics and Technology,3rd international workshop on physics and technology of thin films.
3. Sigmund. (1969) Theory of sputtering. I. Sputtering yield of amorphous and polycrystalline target”, physical review, (148), (2), 383 – 416.
4. Gillen,D. R.; Graham,W.G. and Goelich,A. (2002),“Sputtering of copper atoms by keV atomic and molecular ions: A comparison of experiment with analytical and computer based models” Nuclear Instruments and Methods in Physics Research B 194 , 409– 416.
5. Kirk,A. Zoerb (2007) ,Differential sputtering yields of refractory metals by ion bombardment at normal and oblique incidences, M. Sc Thesis, Colorado State University.
6. Ziegler. F.; Biersack J. P. and Ziegler. D. (2012) ,SRIM: The Stopping and Range of Ions in Matter, Lulu. Com.
7. Nakles M. R.; (2004), Experimental and Modeling Studies of Low-Energy Ion Sputtering for Ion Thrusters, M. Sc Thesis, Virginia Polytechnic Institute and State University.
8. V.S. Smentkowski, , Wei, C., and Browall, K. , (1999). "Summary of Sputter Yield Literature", General Electric Research and Development Center, General Electric Company.
9. J . Orloff, M . Utlaut, and L .Swanson, (2003), High Resolution Focused Ion Beams: FIB and its Applications, Kluwer Academic/Plenum Publishers, NY.
10. M .Nastasi, JW. Mayer and JK .Hirvonen, (1996)."Ion-Solid Interactions: Fundamentals and Applications", Cambridge University Press, Great Britain.
11. Guping D.; Tingwen X. and Yun L. (2012) Preferential sputtering of ion processing SiO2 mirror, AOMATT, The 6th SPIE International symposium on advanced optical manufacturing and testing technologies.