2554

CHARACTERISTICS OF TANTALUM NITRIDE THIN FILMS ON GLASS AND POLYIMIDE SUBSTRATES DEPOSITED BY REACTIVE SPUTTERING

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Electrical Engineering
Department of Electrical Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2011

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(CHARACTERISTICS OF TANTALUM NITRIDE THIN FILMS ON GLASS AND POLYIMIDE SUBSTRATES DEPOSITED BY REACTIVE SPUTTERING) .

: . . , 44 .

(TaN)

TaN

TaN (PI)

Ar N_2

X-Ray Diffraction (XRD) Atomic Force Microscope (AFM) 4-point probe stylus profilometer

XRD TaN (111) (200)

N_2

N_2

N_2

PI

.

2554

5270806621 : MAJOR ELECTRICAL ENGINEERING
KEYWORDS : TANTALUM NITRIDE / POLYIMIDE / REACTIVE SPUTTERING

SAMATCHA VORATHAMRONG : CHARACTERISTICS OF TANTALUM NITRIDE THIN FILMS ON GLASS AND POLYIMIDE SUBSTRATES DEPOSITED BY REACTIVE SPUTTERING. THESIS ADVISOR : ASSOC. PROF. SOMCHAI RATANATHAMMAPHAN, Ph.D., 44 pp.

Tantalum nitride (TaN) has wide range of applications in electronics industry due to its interesting properties, such as high mechanical strength, chemical inertness and thermal stability at high temperature. In this research, thin films of Tantalum nitride were deposited on glass and polyimide substrates by reactive sputtering method under N_2/Ar atmosphere. Gas mixture, sputtering power, and working pressure were varied as processing parameters. Crystal structure, surface morphology, electrical resistivity and deposition rate of the films were investigated by X-Ray Diffraction (XRD), Atomic Force Microscope (AFM), 4-point probe method, and stylus profilometer.

XRD results showed that TaN (111) and (200) was formed when N_2 was introduced to the system. Film crystal structure gradually transformed to amorphous while increasing the amount of N_2. Surface morphology, electrical resistivity, and deposition rate also correlate with N_2 ratio. Deposition rate increases monotonically with an increase in sputtering power. Working pressure influences in lower deposition rate. Effect of substrate results in difference deposition rate and crystal properties of the films on glass and PI substrates.

Department : Electrical Engineering .... Student's Signature ....
Field of Study : Electrical Engineering .... Advisor's Signature ....
Academic Year : 2011 ....

MEKTEC

1

1.1

[1]

[2]

,

[3]

(Integrated Circuit) [4] (Diffusion Barrier) [5]

[6] Chemical Vapor Deposition (CVD) [7] Ion beam assisted deposition [8] sputtering [9] reactive sputtering

1.2

reactive sputtering

(PI)

sputtering

AFM Stylus

Profilometer XRD 4-point probe

1.3

reactive sputtering

2

sputtering

2

sputtering

1.4

1.4.1

sputtering

1.4.2

2

1.4.3

sputtering

2

stoichiometry

2.1

(Ta)

V (N)

electronegativity

5 [10]

( ) Covalent nitrides

electronegativity

( ) Intermediate nitrides (VII VIII)

( ) Saltlike (Salinic) nitrides

- 3

electronegativity

stoichiometry

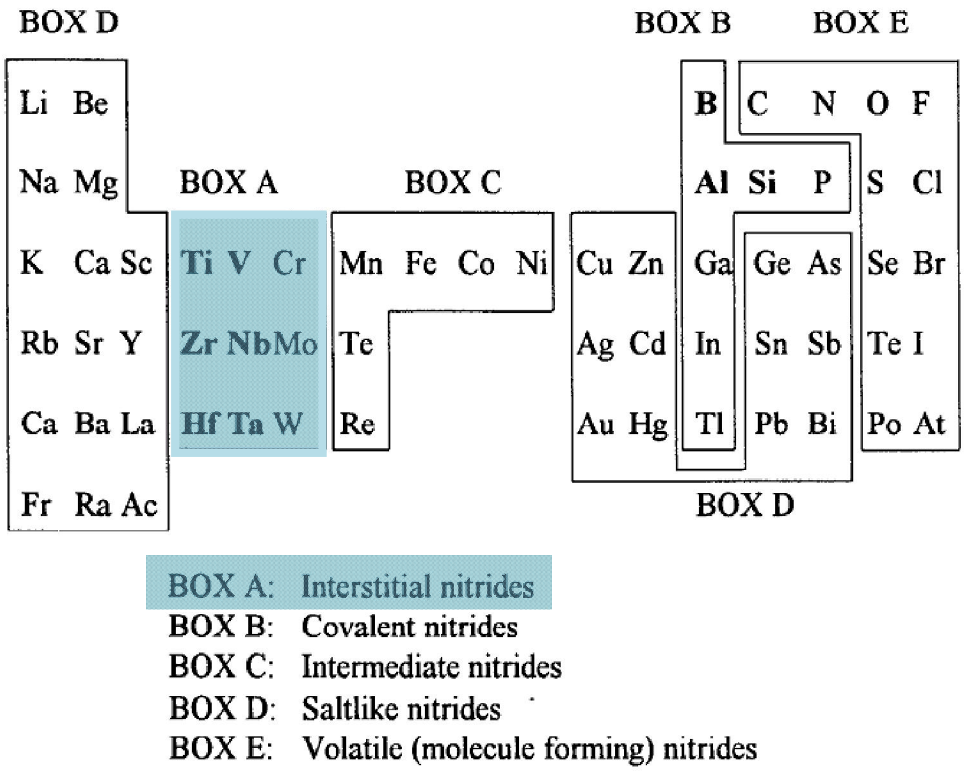
( ) Volatile nitrides

6 7

( ) Interstitial nitrides

electronegativity

(interstitial site)



2.1 [11]

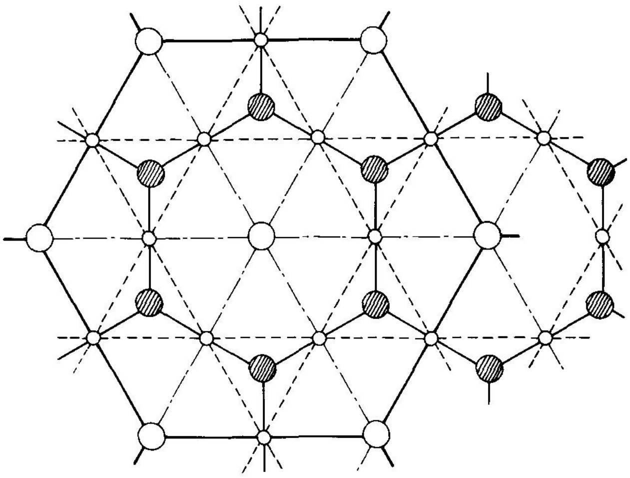
2.1.1

hexagonal a =

5.1808 A˚ c = 2.9049 A˚

Interstitial site

(Octahedron)



2.2 hexagonal ~

$\frac{1}{2},\frac{2}{3},\frac{1}{2}$ $\frac{2}{3},\frac{1}{3},\frac{1}{2}$; •

0,0,0 . [12]

close pack

bcc 0,0,0

14 $\frac{1}{2},\frac{2}{3},\frac{1}{2}$ $\frac{2}{3},\frac{1}{3},\frac{1}{2}$

11

2.1.2 Stoichiometry

interstitial site

(stoichiometric ratio)

Interstitial defect

MN_x M

N x 1

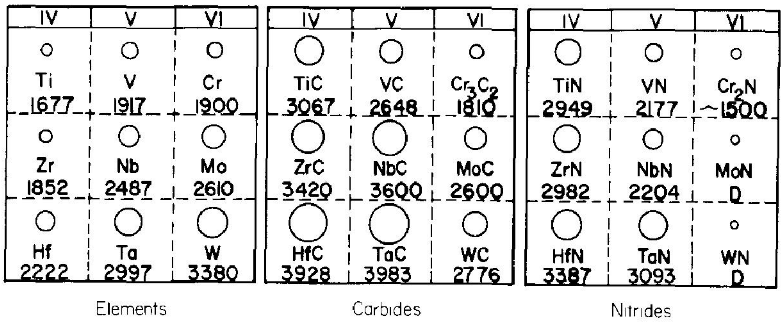
x 1

stoichiometry

2.1.3

Interstitial nitrides

IV V



2.3 Interstitial nitrides carbides

D

800 [13]

Interstitial

(refractory) [14]

"Refractory nitrides"

2.1.4

Interstitial nitrides

1) (M-N)

Interstitial nitrides

stoichiometry (2.1.2)

2)

3)

Interstitial nitrides

2.2

2.2.1 Ion beam assisted deposition

Ion beam assisted deposition

(target)

chamber

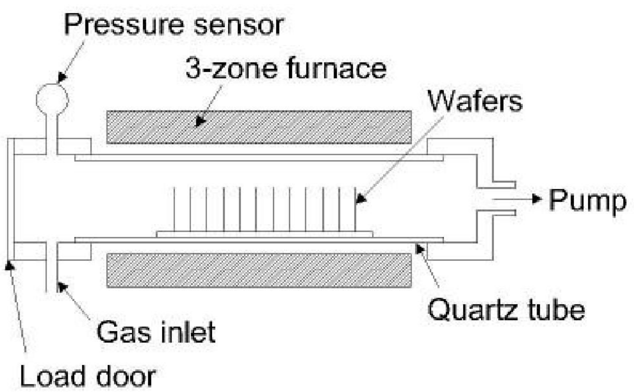
2.2.2 Chemical Vapor Deposition (CVD)

(reactive gas) NH_3 UV

CVD

chamber

chamber



2.4 CVD [15]

CVD

2

1) 2

2)

2.2.3 sputtering

sputtering (Physical Vapor Deposition)

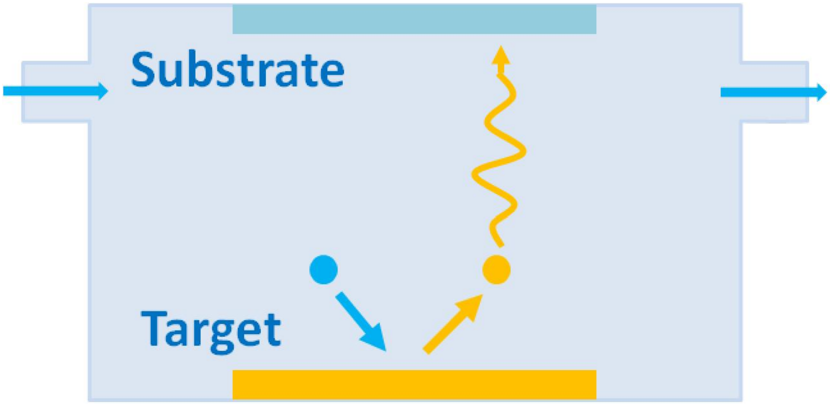
CVD sputtering

(target)

chamber

Ar chamber

discharge



2.5 sputtering

(target)

(substrate)

sputtering

chamber

glow discharge

sputtering deposition DC ,

RF Magnetron Sputtering

DC sputtering sputtering

(dc power source)

discharge

RF sputtering DC sputtering Radio

Frequency (RF) discharge

sputtering

Magnetron sputtering sputtering

gas discharge

sputtering

Reactive sputtering sputtering

chamber

reactive sputtering

chamber

3

3

2

3.1 sputtering

3.2

3.1 sputtering

reactive sputtering UNIVEX350 (Center of Research and Technology Development) Mektec

3.1.1

1

2 chamber sputtering

3 chamber 4.5×10^{-5} mbar

4 (flow rate) 50 sccm
Glow discharge

5 10
Glow discharge 5

6 flow rate 20 sccm
sputtering 200 W 10
sputtering 1.6 × 10^{-2} mbar 1

6 chamber

7

flow rate
flow rate
1.6 × 10^{-2} mbar
0.0 – 27.8%

3.1.2
PI

3.1.1
Polyimide (PI)
PI
3.1.1

3.1.3 sputtering

PI

3.2

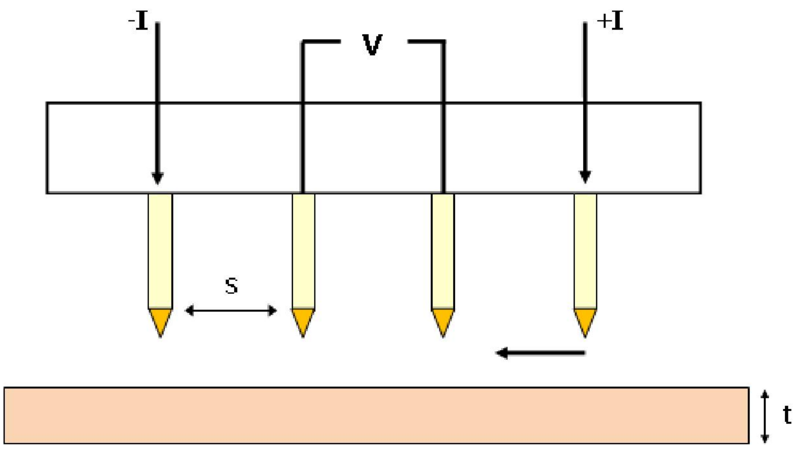
3.2.1 4-point probe

4-point probe

(Bulk) 4-point probe

(probe) 4 2

2 3.1



3.1 4-point probe

probe

probe 4

probe probe s

probe t

-

($t >> s$) (ρ)

$$\rho = 2\pi s\left(\frac{V}{I}\right) \quad (3.1)$$

-

($t << s$) (ρ)

$$\rho = \frac{\pi t}{ln\,2}\left(\frac{V}{I}\right) \quad (3.2)$$

sheet resistivity (R_s)

$$R_S = k\left(\frac{V}{I}\right) \quad (3.3)$$

k geometric factor

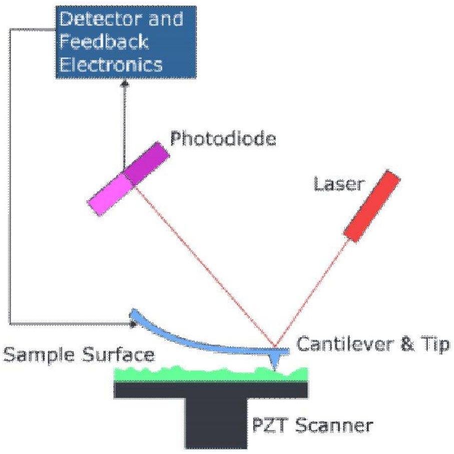
4.53 $\frac{\pi}{ln\,2}$ k

3.2.2 Atomic Force Microscope (AFM)

(cantilever)

(tip) (Si) (Si_3N_4) tip

(Photodiode) (Laser)



3.2 AFM [16]

AFM

- Contact mode

- Noncontact mode

Piezoelectric

- Tapping mode Contact mode Noncontact mode

Contact

mode Noncontact

mode

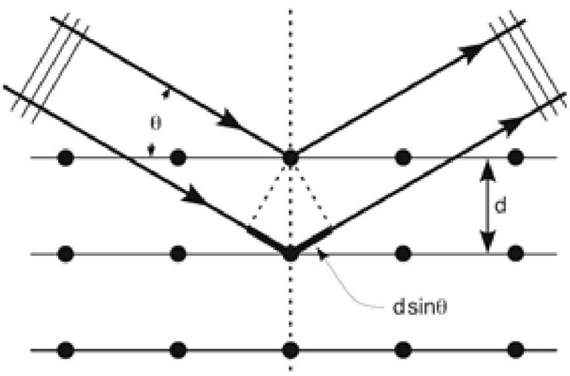
Atomic Force

Microscope Seiko FTA400 Semiconductor Device Research Laboratory

3.2.3 X-Ray Diffraction Analysis (XRD Analysis)

XRD

Bragg



3.3 Bragg (d) [17]

Bragg's Law : $2d \sin \theta = n\lambda$ (3.4)

d

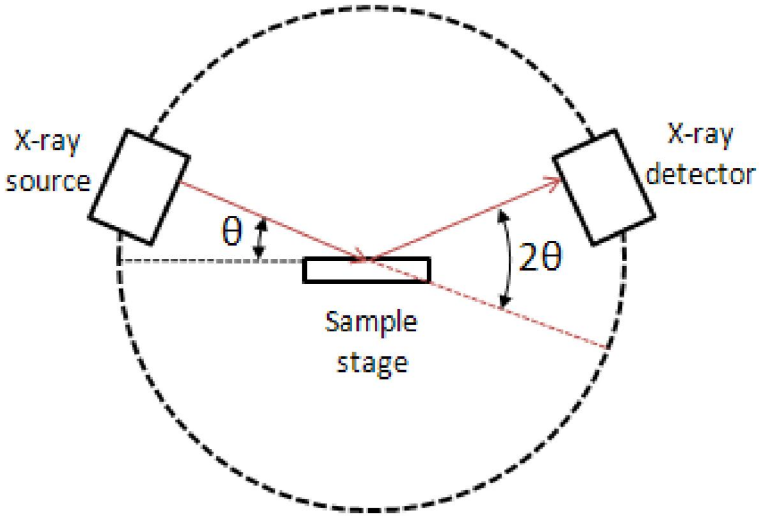
θ

n 1, 2, 3, 4, …

λ

(2θ)

(peak)



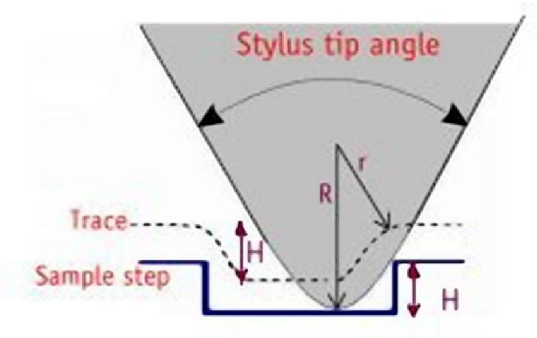
3.4 X-Ray Diffraction Analysis [18]

X-ray
Diffractometer Rigaku (SA-HFM3) Innovative materials research unit

3.2.4 Stylus Profilometer

Stylus

AFM Stylus Profilometer



3.5 Stylus Profilometer [19]

Stylus Profilometer
Stylus

4

3 4.1

4.2

PI 4.3

4.1

4.1.1 XRD

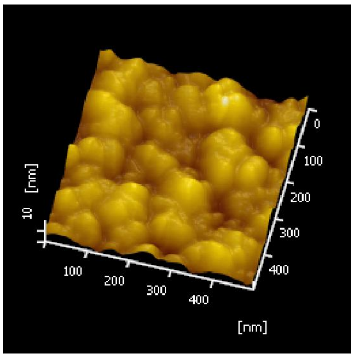
XRD (crystal)

XRD peak (111)

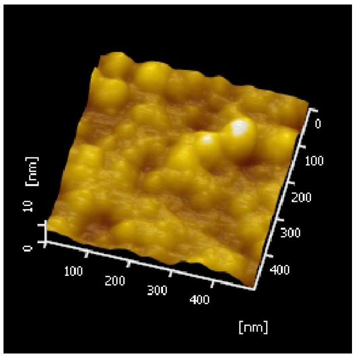
(200) peak

(Amorphous)

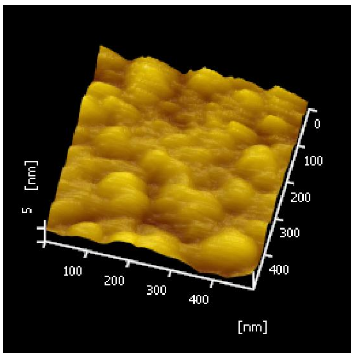
4.1.2 AFM



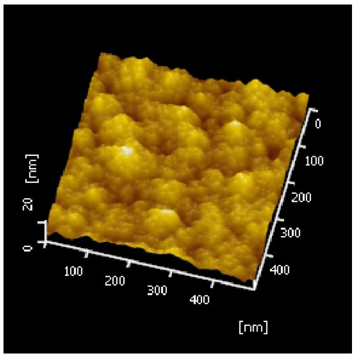
(a)



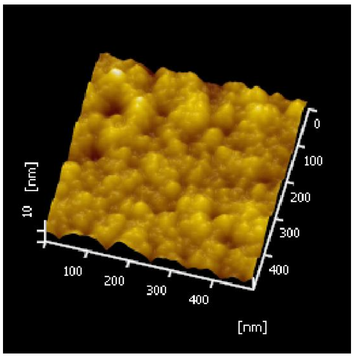
(b)



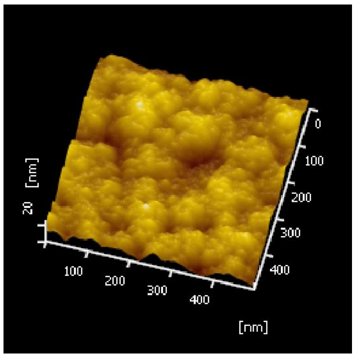
(c)



(d)



(e)



(f)

4.1 AFM

0.0% (a) 5.0% (b) 10.5% (c) 15.8% (d)

22.2% (e) 27.8% (f)

AFM

(N_2 = 0.0%) 50 nm

5.0% 100 nm

5.0 – 22.2%

nucleation site nucleation

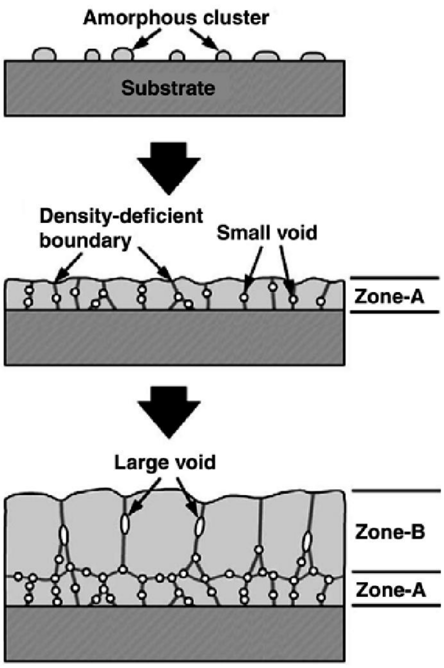
site nucleation site

[21]

nucleation site [22]

nucleation site

amorphous 27.8%



4.2 nucleation site (a)

nucleation site (b)

(c) [23]

4.1.3

Percentage of N_2 (%)	Deposition Rate (μm/hr)
0.0	3.96
5.0	1.85
10.5	1.5
15.8	0.6
22.2	0.5
27.8	0.4

4.1

1 . 0.5 – 4.0 μm/

Leszek Gladczuk et al. [24]

sputtering sputtering sputtering

yield (S)

(4.1)

$$S = \frac{\text{target (atoms removed)}}{\text{(incident ions)}} \quad (4.1)[25]$$

chamber sputtering yield

sputtering yield

sputtering yield

sputtering yield

(4.2)

$$S = k \frac{1}{\lambda \cos\theta} \frac{M_1 M_2}{(M_1 + M_2)^2} E \qquad (4.2)[26]$$

k

λ mean free path

θ target

M_1

M_2 target

E

Almen [27]

$$S \propto \frac{M_1}{M_2} \frac{\ln E}{E} \frac{1}{\cos\theta} \qquad (4.3)$$

sputtering yield M_1

reactive sputtering M_1

40 7

M_1 sputtering yield

4.1.4 4-point probe

Percentage of N_2 (%)	ρ(μΩ.cm)
0.0	150
5.0	250
10.5	210
15.8	245
22.2	360
27.8	700

4.2

0.0%

150 μΩ.cm

250 μΩ.cm

5.0 – 22.2%

[28]

4.1.1 4.1.2 27.8%

[29]

4.2

PI

3.1.1

PI

3.1.1

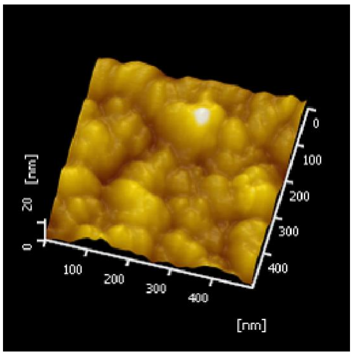
PI

4.2.1 XRD

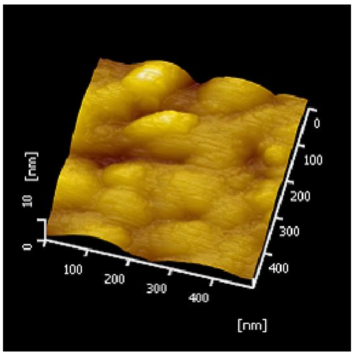
XRD PI

22.2% 4.2.2

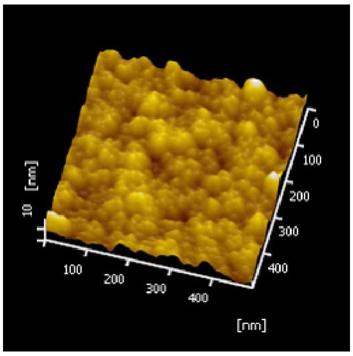
4.2.2 AFM



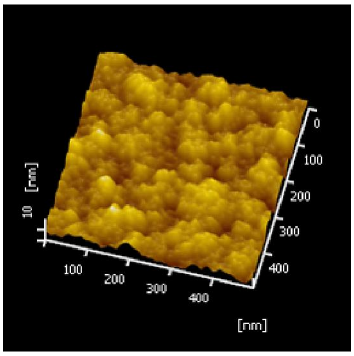
(a)



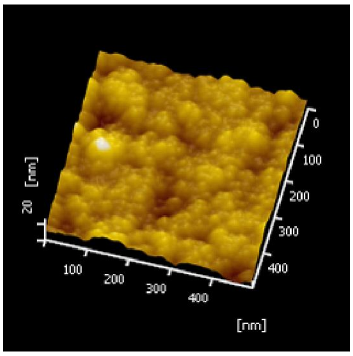
(b)



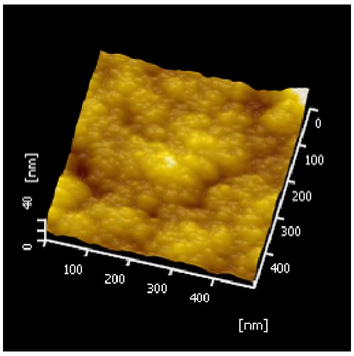
(c)



(d)



(e)



(f)

4.3 AFM PI 0.0% (a) 5.0% (b) 10.5% (c) 15.8% (d) 22.2% (e) 27.8% (f)

PI

4.1.2

PI XRD

PI

surface energy

surface energy 1000 mN/m

PI surface energy 40 mN/m [30]

nucleation site

nucleation site

nucleation site

(a) (b)

4.4 nucleation site (a)

PI (b)

4.2.3

Percentage of N_2 (%)	Deposition Rate (µm/hr)
0.0	2.91
5.0	1.64
10.5	1.68
15.8	0.5
22.2	0.45
27.8	0.35

4.3 PI

PI

4.1.3

PI

surface

energy PI

PI

4.2.4 4-point probe

Percentage of N_2 (%)	ρ ($\mu\Omega$.cm)
0.0	145
5.0	260
10.5	250
15.8	380
22.2	680
27.8	710

4.4 PI

PI

150 – 700 $\mu\Omega$.cm PI

22.2%

4.2.1

4.2.2

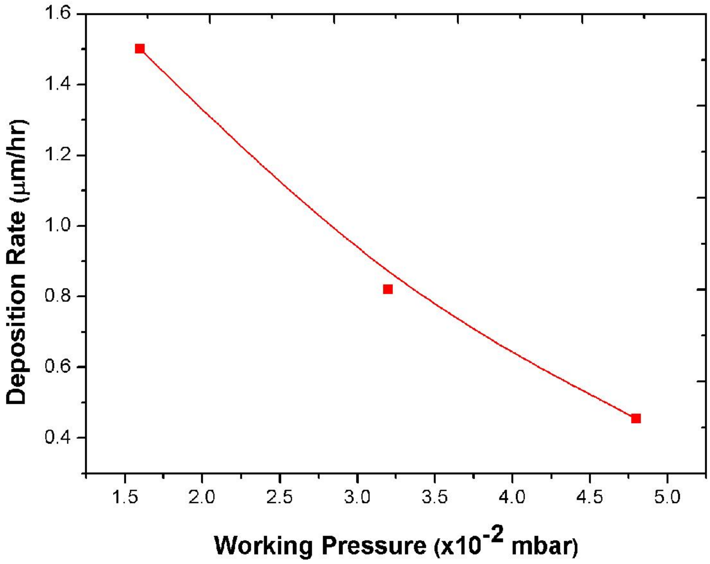
4.3

sputtering

5.0% 5.0%

PI

4.3.1



4.5

sputtering

(R)

$$R = \frac{W}{t} \tag{4.4}$$

W sputter

t

W (4.5)

$$W \approx \frac{k_1 W_0}{pd} \tag{4.5}$$

k_1

W_0 sputter

p

d electrode

sputtering

$$R \propto \frac{1}{p} \tag{4.6}$$

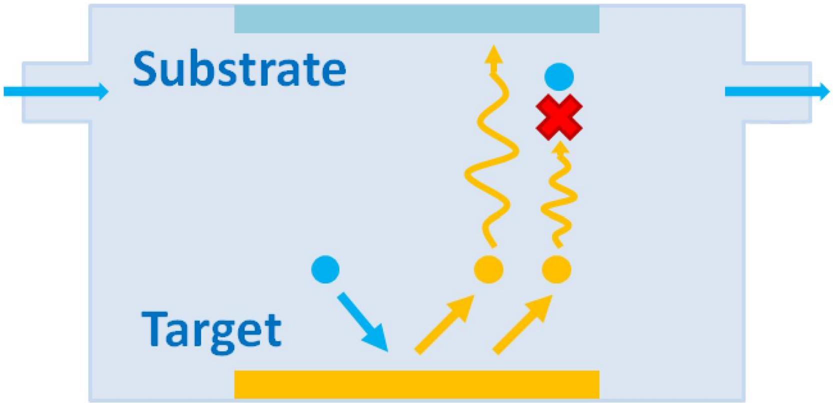
(4.6)

sputtering

sputter

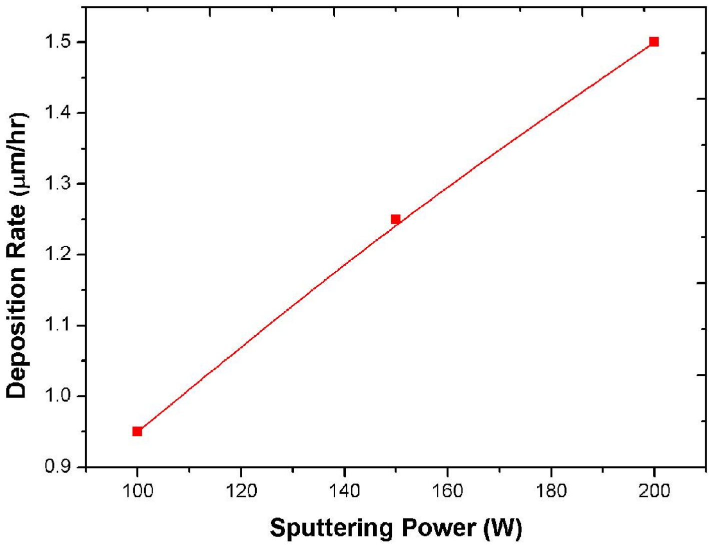
discharge

sputter



4.6 sputtering

4.3.2



4.7

4.13 sputtering

A.

Aryasomayajula et al. [32] sputtering yield

4.1.3

$$S = k\frac{1}{\lambda\cos\theta}\frac{M_1M_2}{(M_1+M_2)^2}E \qquad (4.7)$$

(4.7) sputtering yield (S)

(E) sputtering

5

2

XRD AFM Stylus

Profilometer 4-point probe

peak

(111) (200) XRD

peak nucleation site

peak

4-point probe

sputtering

sputtering

target

surface energy

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