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Performance Evaluation of TiAlN and CrN Coated Silicon Wafer by Magnetron Sputtering Method

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Abstract

Silicon wafer is used for solar cells and microelectronics application as it is provides more energy as compared to conventional material. Properties of silicon wafer can further improve by applying various hard coating on its surface. Current work reflects property comparison of TiAlN and CrN coated silicon wafer by magnetron sputtering process. Silicon wafer with (1 0 0) was selected as a substrate material, Ti:Al(50:50) target for TiAlN coating and 99.9% pure Cr target for CrN coating was used for deposition. The coating was prepared with different gas proportion with working pressure 8×10^{-3} mbar with controlled rate of deposition of 0.1 A^0/S. Deposition temperature was 400^0 C and 80 nm coating thickness developed during deposition. Atomic Force Microscopy was used to analyze the surface topography. It reveals that TiAlN coated silicon wafer has lowest roughness 10.8nm and highest roughness 16.9nm as compared to CrN coated silicon wafer which has lowest roughness 28.4nm and highest roughness 124nm.

Keywords: Silicon wafer, Gas ratio, Magnetron sputtering coating

INTRODUCTION:

Nitride based thinfilm deposition on silicon substrate improves it surface properties such as surface roughness. Selection of substrate material such as titanium nitride, chromium nitride, titanium aluminum nitride, titanium silicon nitride, chromium silicon nitride etc. is depends on application on which it need to utilize. Nitride base coating are generally used to protect the substrate against diffusion, wear, corrosion and high temperature [1-12].

Magnetron sputtering process was used for deposition of Chromium Silicon Nitride and Chromium Nitride on Silicon and Steel substrate materials by Shah *et al* [13]. It was noted that growth of columnar type occurred on Chromium Silicon Nitride substrate as it has nano-crystalline grains of Chromium Nitride. Changing crystalline sizes found that it became denser with increase in nitrogen and addition of some portion of Silicon. Roughness of surface was observed to be affected by Nitrogen and it was noted that it decreases as the Nitrogen content increases. For SA304, Surface roughness, measured in RMS value, was noted as 69 to 28 as temperature increased from 373 K to 773 K. On the other hand, for Silicon it was noted 25 to 11. The hardness of Chromium Silicon Nitride coatings was recorded and it was observed that it increases from 2392 HV to 2570 HV as the Silicon content increases. Thin films of uni-phase Chromium Nitride were observed with very high N_2 content (above 40%) in the deposition chamber. The hardness value of Cr_2N (at 30% N_2 content in the chamber) phase was recorded to be higher than the CrN (above 40% N_2 content) phase [13-18].

Argon and nitrogen gases were used by Shah *et.al* for deposition at varying temperatures viz. 200 ^{0}C,300 ^{0}C and 400^0 C for Chroium Nitride and Chromium Silicon Nitride coating. It was observed that at 60:40 Ar:N_2 gas ratio, hardness value was recorded as 2100 VHN. This also revealed hexagonal structure, lower surface roughness and porosity of Chromium Nitirde coating. In addition, it was also observed that hardness in a pure nitrogen atmosphere was recorded higher 2700 VHN. Chromium Silicon Nitride coating indicated hardness of 2800 VHN as it possessed 6.33 atomic silicon contents which inturn has the influence to improve hardness. Hardness was observed to improve in both types of coatings due to grain size reduction, denser morphology and reduction in the surface roughness of the substrate. It was observed that microstructural property of coated substrate was influenced by parameters of process such as temperature of substrate, pressure and power consumed for deposition. Experimental investigation was carried out on wear and hardness property of Chromium Aluminium Nitride coated SA304 substrate deposited by magnetron sputtering process. Nano-indentation was performed by “Pin-on-disc” tribometer. On the other hand, hardness was studied using nanoindentation technique for various proportions of Aluminium content. It was observed that with an increase in Aluminium content in (1 1 1) orientation was achieved. It was also seen that it reveals highly textured Chromium Nitride orientation in Chromium Nitride coated substrate. It was observed that with an increase in Al content grain size increases and lower surface roughness is achieved. Friction co-efficeint for Chromium Nitride coating was 0.644 and for CrAlN, it was 4.8, which indicates presence of better tribological properties [19-22].

Aim of present work is to study the effect nitrogen and argon gas ratio on surface property of silicon substrate by magnetron sputtering process and also compare the surface morphology of TiAlN deposited and CrN deposited silicon substrate.

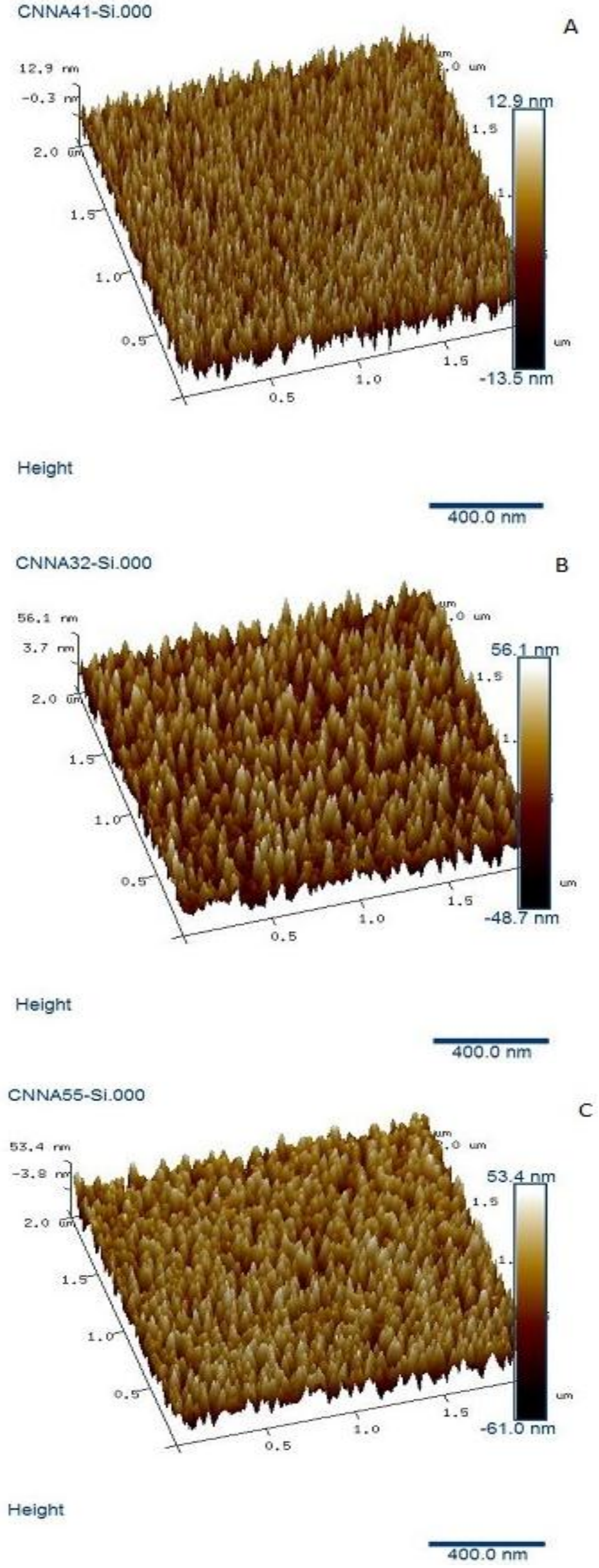
EXPERIMENTAL WORK:

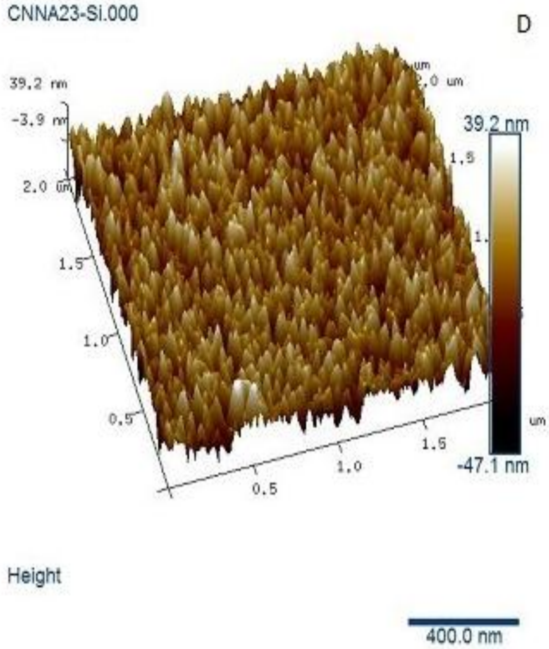
Magnetron sputtering method was used among the physical vapour deposition process to generate coating on silicon material. Silicon substrate of orientation (1 0 0) of size 10 mm × 10 mm is used to develop thin film of TiAlN and CrN coating. Ti:Al (50:50) target for TiAlN coating and 99.9% pure Cr target for CrN coating was used for deposition. Prior to deposition surface was cleaned ultrasonically. Distilled water is used to clean the surface for 20 minutes and then Hf solution is applied to remove impurities from the surface. Proportion of H_2O: Hf of 1:1 for 5 minutes was used to prepare Hf solutions.

Magnetron sputtering machine of advanced process technology is used to generate TiAlN and CrN deposition on silicon substrate. Target of Ti:Al(50:50) and 99.9% purr Cr targets inserted into the chamber, parameter for both types coating was consider uniform. Sample was mounted properly in the middle of the cahmber. To synthesis both coating chamber was first evacuated to a pressure of 8×10^{-6} mbar. After evacuating the chamber nitrogen and argon gas was introduced at five different ratio of N_2:Ar of 80:20,60:40,50:50,40:60,and 20:80. To develop 80 nm coating thickness on silicon substrate deposition rate was maintained 0.1 A^o/S with rotation of 2 to 3 RPM. Working pressure for sputtering was 8×10^{-3} mbar and time taken to develop one set of coating was 143 minute. The ions have been accelerated directly from target to sample and it develops coating at 400^0C temperature. A digital microscope Atomic Force Microscope was used for study of surface morphology TiAlN and CrN coated silicon substrate at variable gas ratio. Atomic Force Microscope provide the details of surface roughness, growth of deposition as well as average size of coating.

RESULT AND DISCUSSION:

Surface roughness and morphology are the important parameter to analyze coated surface of any substrate. It provides the detail growth and structure of surface. Properties like friction, wear, cohesion, adhesion etc. are the parameters which are directly correlated with the quality of surface. Geometry and texture of any coated surface can be evaluated by analysis of surface roughness [23-25].


CNNA41-Si.000
A
12.9 nm
-13.5 nm
Height
400.0 nm
CNNA32-Si.000
B
56.1 nm
-48.7 nm
Height
400.0 nm
CNNA55-Si.000
C
53.4 nm
-61.0 nm
Height
400.0 nm



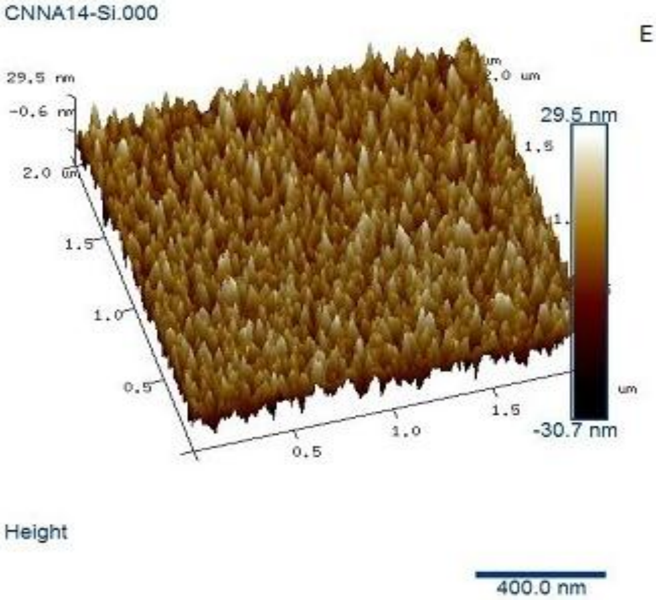
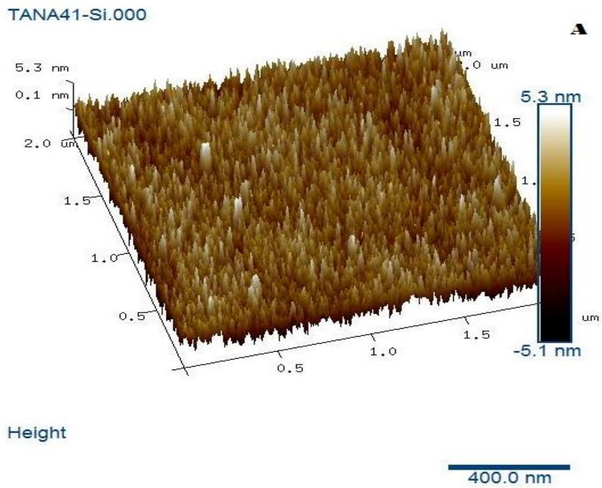


Figure 1: 3-D Images of CrN coated Silicon wafer at variable N_2:Ar gas ratio(A) 80:20,(B) 60:40,(C) 50:50,(D)40:60 and (E) 20:80


TANA41-Si.000
A
5.3 nm
0.1 nm
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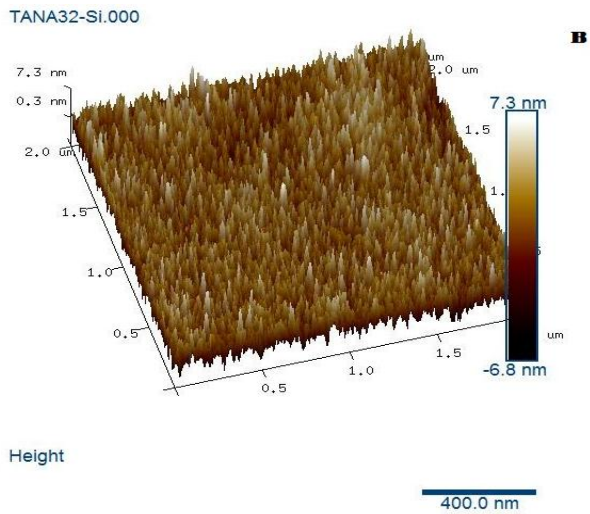
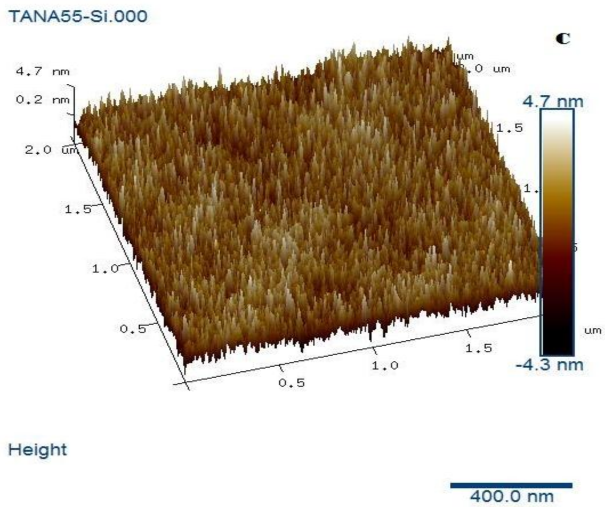
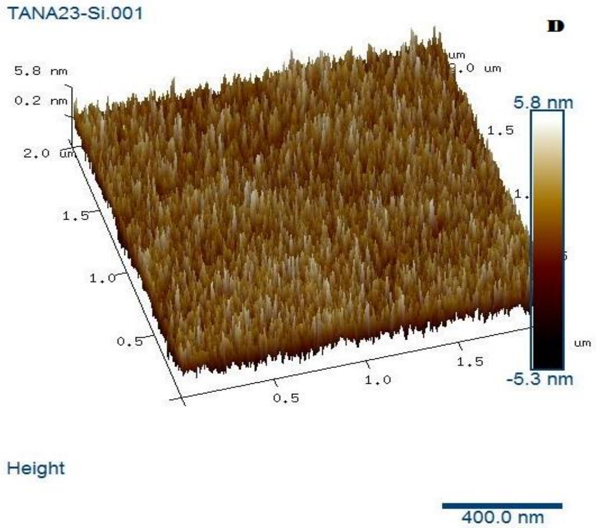
400.0 nm


TANA32-Si.000
B
7.3 nm
0.3 nm
2.0 um
1.5
1.0
0.5
0.5
1.0
1.5
7.3 nm
-6.8 nm
Height
400.0 nm


TANA55-Si.000
C
4.7 nm
0.2 nm
2.0 um
1.5
1.0
0.5
0.5
1.0
1.5
4.7 nm
-4.3 nm
Height
400.0 nm



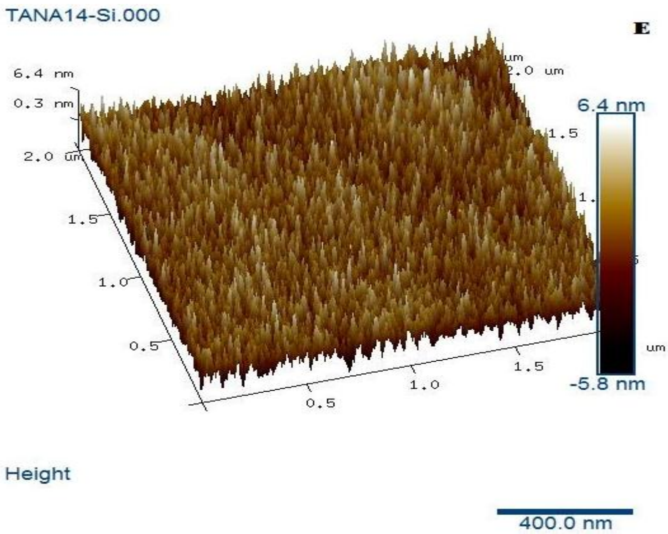


Figure 2: 3-D Images of TiAlN coated Silicon wafer at variable N_2:Ar gas ratio(A) 80:20,(B) 60:40,(C) 50:50,(D)40:60 and (E) 20:80

As shown in fig.1 and fig.2 Atomic Force Microscope is used for analyze effect of nitrogen to argon gas ratio surface morphologies of TiAlN and CrN coated silicon substrate. Surface topographical of CrN deposited silicon material at variable N_2: Ar gas ratio is shown by fig.1 and fig.2 describes surface analysis TiAlN coated substrate. For all type of coating it shows uniform and dense structural morphological growth, but average size and prolongation was varied for TiAlN and CrN at different gas ratio. The average grain size of CrN coating is higher than TiAlN coating. The surface of TiAlN coating is more compact as compared to CrN surface.

Table 1: Roughness of CrN and TiAlN coated Silicon substrate at different gas ratio

Sample	N_2:Ar Gas ratio	R_a(nm)	R_q(nm)	Max. Roughness(nm)
CNNASi41	80:20	3.23	3.98	28.4
CNNASi32	60:40	12.9	15.9	112
CNNASi55	50:50	14.0	17.3	124
CNNASi23	40:60	9.69	12.3	114
CNNASi14	20:80	7.02	8.74	69.9
TANASi41	80:20	1.17	1.47	15.4
TANASi32	60:40	1.60	2.01	16.9
TANASi55	50:50	1.02	1.28	10.8
TANASi23	40:60	1.25	1.57	13.5
TANASi14	20:80	1.39	1.75	14.7

Table 1 shows that for CrN deposition with increasing nitrogen and argon gas content number of prolongation increasing, while its size decreasing. The average grain size of coating deposited at 80:20 gas ratio of nitrogen and argon exhibits lowest as compared to grain size at other combination. Surface morphology at 80:20, 20:80 and 40:60 observed more compact other than 50:50 and 60:40 gas ratio of N_2:Ar.Opposite behaviour was revealed for TiAlN coated substrate that lowest size observed at 50:50 N_2:Ar gas ratio.

It shows that more homogeneous and smoother surface structure observed for TiAlN coated silicon material as compared to CrN deposited substrate. Rq is the Root Mean Square roughness and it provides the finishing of optical surface. Ra is average roughness, which describe roughness of machine surface [26-28]. Table gives maximum roughness, Rq and Ra of CrN and TiAlN coated substrate. It reveals that Nitrogen and Argon ratio is the major aspects of decreasing or increasing surface roughness and grain size of coating. Substrate deposited by CrN material has Ra value decreasing by increasing N_2 or Ar gas content, while surface roughness increasing with rising N_2 or Ar gas proportion. RMS has been found lowest at 80:20 gas ratio and highest at 50:50 gas ratio of N_2: Ar.

Substrate deposited by TiAlN coated gives better result at equal proportion of nitrogen and argon gas. With increasing nitrogen gas content surface morphology is improving as compared to other type of gas ratio. Lowest average grain size of 4.7 nm and surface roughness 1.07 nm observed at 50:50 N_2:Ar gas ratio.

CONCLUSION:

At the same condition and gas ration TiAlN coated surface gives more compact and better surface morphology observed as compared to CrN coated silicon substrate. For all types of gas ratio columnar growth and denser surface structure observed for CrN and TiAlN coating. Least average grain size 1.02 nm observed at 50:50 N_2:Ar gas ratio for TiAlN coating, while lowest average grain size 12.9 nm for CrN coating at 80:20 N_2:Ar gas ratio. Current work reveals that for TiAlN coating equal proportion of Nitrogen and Argon gas ratio gives excellent result and for CrN coating 80:20 gas ratio gives good surface morphology.

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