Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 February 2018 doi:10.20944/preprints201802.0040.v1

Hard Coating is Because of Oppositely Worked Force-Energy Behaviors of Atoms

Mubarak Ali [a] *, Esah Hamzah [b], Mohd Radzi Mohd Toff [c]

[a] Department of Physics, COMSATS Institute of Information Technology, Islamabad, 45550, PAKISTAN, *E-mail: mubarak74@comsats.edu.pk, mubarak74@mail.com

[b] Department of Materials, Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA, E-mail: esah@fkm.utm.my

[c] Advanced Materials Research Center (AMREC), SIRIM Berhad, Lot 34, Jalan Hi-Tech 2/3, Kulim Hi-Tech Park, 09000 Kulim, Kedah, MALAYSIA, E-mail: mradzit@sirim.my

Abstract –Coatings of specific materials in few atoms of thickness to several microns on certain substrate is the basic need of society and they attend the regular attention of scientific community working in different domains; decorative and protective coatings, transparent and insulating coatings, coating medical implants and surgical instruments, coatings for drug delivery and security purposes, ultra-precision machine coatings, coating cutting tools, coatings for MEMS and NEMS, and so on. Different coatings develop under significant composition of atoms where certain force-energy behaviors provide the provision for electrons (of gas atoms) to deal double clamping of energy knots of unfilled states (of solid atoms). Under certain process conditions, different nature atoms oppositely-switch force-energy behaviors to the ones originally owned where they locate common mid-points of their ground points at accommodating level resulting into deal binding. Because of adjusting contraction-expansion of clamping energy knots under varying potential energy of electrons, they develop structure of their atoms termed as hard coating, which is known since antiquity. Different properties and characteristics of hard coatings like hardness, adhesion, roughness and friction coefficient, etc. are emerged under attained mid-points of transformed atoms in evolving structure. This work describes the science of depositing hard coating opening several new areas.

Keywords: Hard coating; TiN; Atomic nature; Expansion and contraction of clamping energy knot; Potential energy of electron; Ground point; Structure evolution

1. Introduction

Hard coatings are the integral part of scientific research along with technological advances. It is learnt routinely that marketable hard coatings for different usages are involved in different sorts of materials and deposition technique. In this context, several materials and their deposition techniques to deposit at suitable substrates and tools are available in the literature discussing and explaining both deposition history as well as application. In coatings, a minute deposited quantity of materials over less-important material solves the purpose of giving value-added results, often, in an astonishing way.

A variety of techniques are involved for depositing different sorts of hard coatings to suitable tools and substrates. Coatings were mainly employed with two targeted approaches; in the first case, the potential use of external coated part, which is not subjected to a great deal in the uncoated case and in the second case, potential use of internal surface where inner uncoated surface of material was not the subject of great concern but on coating, it became a great deal. Overall, coating the surface of certain material results into deliver its different behavior of functioning.

Atoms of electronic transition do not elongate and those belonging to inert gases split under the excess propagation of photons characteristic current through their certain flowing density [1]. Under attaining certain state behavior, atoms process heat energy to generate photon energy [2]. Depending on the nature of atoms dealing solid behavior, they evolve different basis-structures as per applicable format of force [3]. Formation of different tiny particles under varying conditions of the process reveals the information of registering different dynamics of their atoms [4]. A monolayer triangular-shaped tiny particle was developed under certain conditions which transformed one-dimensional arrays of atoms into structure of smooth elements under the joint application of surface format force and travelling photons of adequate wavelength [5]. Depending on the atomic behavior of certain tiny-sized particles their role for nanomedicine can either be good or harmful [6]. At suitable precursor concentration, many tiny particles having certain geometry are developed [7]. Shape of tiny particles and particles are being controlled under the application of pulse behavior [8]. Particles of various anisotropic shapes developed in less than millisecond time [9]. Developing tiny particles of certain geometry is being tapped in silver solution and binary composition in addition to gold solution [10]. Predictor packing in developing gold particles is discussed elsewhere [11]. Different atomic behavior of carbon is being registered in tiny grains carbon films under Raman spectroscopy and energy loss spectroscopy [12]. Atomic structure and binding of carbon atoms is pinpointed [13]. Switching morphology-structure in carbon films is discussed elsewhere [14]. Under varying chamber pressure, a discernible change in the morphology and growth rate of carbon films is observed [15].

Depositing TiN coatings under varying process conditions on different substrates while employing a technique known as ‘cathodic arc physical vapor deposition’, a different morphology-structure along with hardness, surface roughness, friction coefficient, adhesion strength and overall performance of coated tools were resulted [16-27]. In addition to those, there are several other available studies in the literature targeting TiN hard coating along with processing technique and analysis [28-35]. In addition to TiN hard coating, studies on different types of hard coatings which were developed under various employed process conditions are also available [36-47]. The basic idea discussed in those studies is related to properties and characteristic of deposited coatings, which are subjected to the change of process parameters, type of material and processing approach, mainly.

The prosperous assembling of colloidal matter into meaningful structure will result into deal atoms and molecules as tomorrow’s materials [48] and understanding in the individual dynamics of tiny-sized particles formation is essential before enabling the assembling to useful large-sized particles [49].

In addition to discussed scientific details of hard coatings, they are in the way to express relation between different atoms. This study reports the fundamental aspect of developing hard coatings at different substrates with emphasis on the formation of TiN hard coating while depositing on a high-speed steel (HSS) disc in arc-based random physical vapor deposition technique. The aim of this work is to present the fundamental aspect of depositing hard coating, in general, and investigation about developing TiN coating deposited on HSS disc in random arc-based physical vapor deposition system.

2. Experimental details

Samples of HSS discs were utilized for the deposition of TiN coating in a commercially available coating unit known as 'cathodic arc physical vapor deposition', which can also be termed as 'random arc-based physical vapor deposition'. After necessary cleaning, the samples (diameter: 10 mm, thickness: 6 mm) were loaded in the coating system mark Hauzer Techno Coating (HTC) 625/2 ARC. The complete deposition procedure along with metallographic process of samples has been described earlier [27].

Surface morphology and interface studies were done using FE-SEM (Model LEO-1525). The thickness of the deposited coatings was measured by using FE-SEM under fracture cross-sectional image. Prior to go for TiN coating, an interlayer of Ti was deposited to gain and enhance the adhesion strength of the following coating, which is for time duration of 15 minutes. At start of depositing inter-layer, the chamber pressure was 5×10^{-6} mbar. While depositing inter-layer, a small amount of N gas flow rate (50 sccm) was being maintained by mass flow controller meter. To deposit TiN coating, substrate temperature was being maintained at 300°C where N gas flow rate was 250 sccm. The bias voltage was 50 volts where rotational speed of the substrate holder was set 60%. The current to ignite arc for ejecting Ti atoms from the metallic target was 100 amps. Total duration of the deposition was 90 minutes.

3. Results and discussion

Figure 1 (a) shows surface morphology of deposited TiN coating on HSS disc where coating surface is partially covered with macrodroplets (MDs) of size ranging from few microns to few hundred of nanometers, which are uniform in their distribution. A large sized macrodroplet (MD) in the central vicinity shows the mapping of the region where identifying the level of concentration of both sort of atoms is related to Ti and N

 doi:10.20944/preprints201802.0040.v1

elements along with their scale of distribution. There are several studies dealing with the reduction of MDs under varying the process parameters along with different strategies [16-19, 22-24].

Figure 1 (b) shows fractured cross-sectional view of the coating where initially deposited Ti layer is observable having thickness less than one micron. Atoms of Ti-interlayer first adhere to atoms of substrate because of their favorable nature to deal binding. Substrate surface where Ti interlayer adheres the elements W, Mo, Cr, V, C, Fe, etc. are involved as discussed elsewhere [16, 23], thus, they bound well to substrate surface by introducing the favorable conditions of forthcoming depositing TiN coating. In this context, the nature of substrate can deal different elements where their different force behaviors can introduce appreciable binding to depositing atoms, thus, governing value-added features of the resulted coating. Adhesion strength of TiN coating deposited under certain conditions in random arc-based PVD system is discussed elsewhere [25, 27].

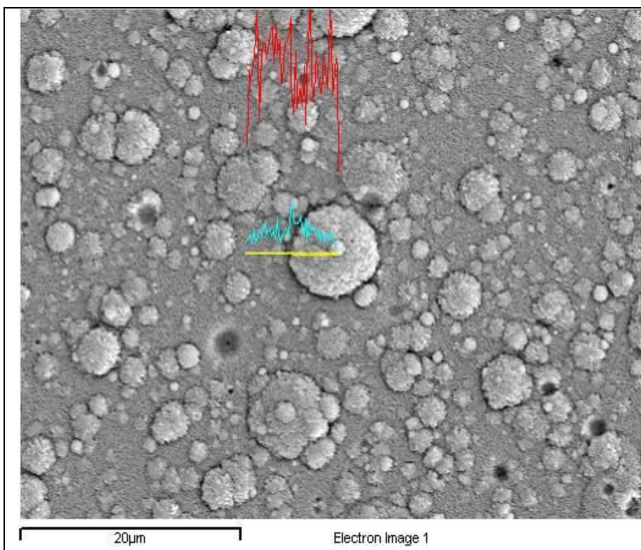

Figure 1 (a): Topography view of TiN coating on HSS

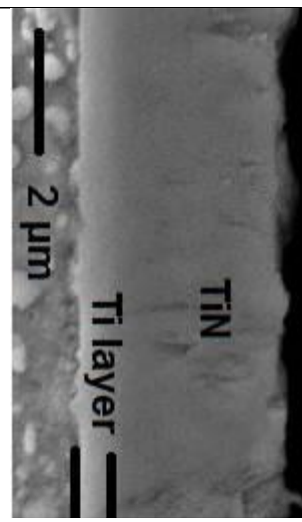

Figure 1 (b): Ti-interlayer of few hundred nanometers shows contrast with respect to substrate and TiN coating thickness ~ 4 µm (a cross-sectional view of coating prepared under metallographic cross-sectioning procedure)

Figure 2 represents the mapping of Ti atoms present in TiN coating at point of MD shown in Figure 1 (a), which is presented in the form of histogram, which shows around 70% of content. This indicates that the area (volume) covered by Ti atoms in the TiN coating at top front surface not only contained 70% of content of metallic element but it is also distributed densely in MD and in uniform manner. This indicates that that MD contained very less concentration of N atoms.

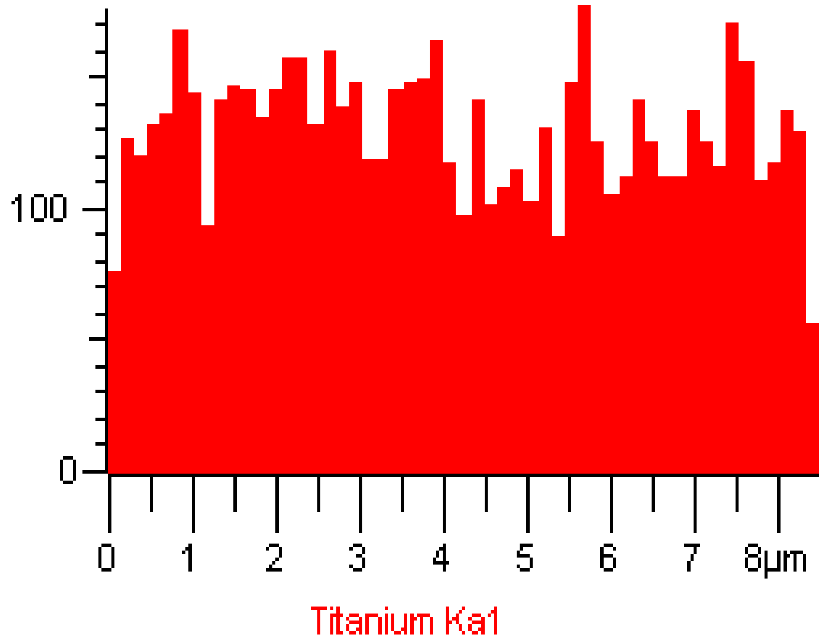

Figure 2: Mapping of Ti atoms distribution along with the ratio of their content

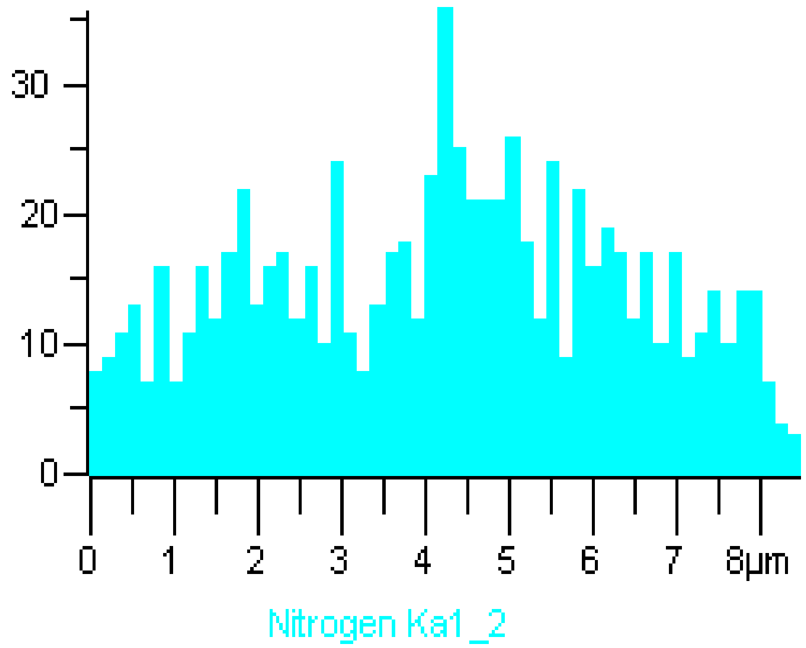

Figure 3: Mapping of N atoms distribution along with the ratio of their content

Figure 3 represents the mapping of N content in TiN coating in the form of histogram showing around 30% of contained area (volume) at the central point of MD shown in Figure 1 (a). This indicates that the area (volume) covered by N atoms in the TiN coating at top front surface not only contained 30% of content but also contained uniform distribution, which is not in the dense manner, but it is in a uniform manner at MD. This indicates that that MD contained approximately three times less concentration of N atoms as compared to Ti atoms.

On incorporating the gas atoms, metallic atoms become poor in conduction where the resulted coatings work as nearly an insulator where enhanced field emission characteristics of propagating photons characteristic current is interrupted, which is the result of non-uniform inter-state electron gap. In this context, the incorporation of N atoms built the bridges through their electron states all around the Ti atoms resulting into lower the propagation of photonic current and further detail regarding inter-state electron gap is given elsewhere [1]. Therefore, the propagation of current no more requires the band gap between conduction band and valence band to explain the science of semiconductor materials or others.

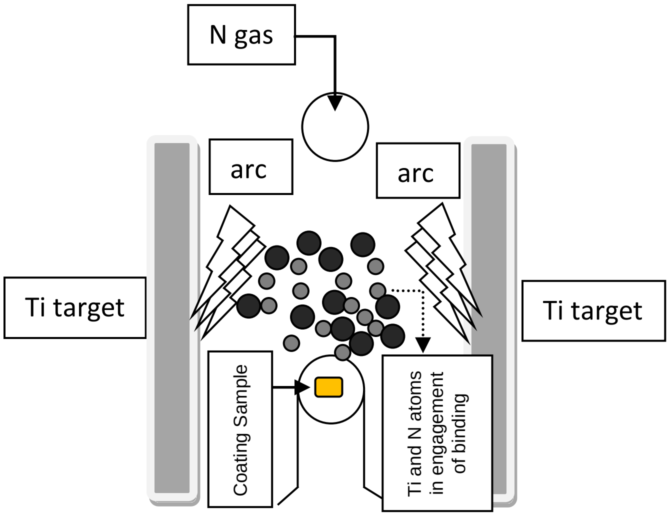

Figure 4: The basic layout of depositing Ti and N as a TiN coating at substrate

At high concentration of N atoms, a random arc is steered for ejecting Ti in atomic form as well as in droplet form depending on the nature of Ti targets along with employed conditions of physical vapor deposition system. In random arc-based PVD system, atoms of Ti (or other metallic nature atoms) are ejected from the surface of different shaped targets where arc supplied the energy. The basic layout of ejecting Ti atoms and entering N atoms to deposit TiN coating is shown in Figure 4.

In different coating technology deposition-based technologies, regardless of that, required numbers of atoms per unit area or volume are depositing under certain tailored parameters, their dealing of energy is placed under individual attained dynamics, and electron-dynamics is the key to determine certain nature of structure in terms of uniformity in the gaining order. However, it appears that formation of TiN structure in order of any homogeneity is within short range order. Thus, the deposited coatings mainly deal the mixed order of structure of atoms of constituted elements. Each Ti atom only occupies two electrons in the outer ring. This low number of filled states allows the Ti atom to occupy many unfilled states of electrons above east-west poles at both left-side and right-side of North Pole. On the other hand, five filled states of outer ring of each N atom allow less number of unfilled states to occupy outer ring. In this context, a N atom contains several filled states of outer ring. Therefore, those several unfilled states of outer ring in each Ti atom provide provision when it is dealing certain transition state to deal double clamping of energy knots for electrons of filled states of outer ring in the N atom under certain transition state and when it is being placed to its suitable location. Two different nature atoms (Ti and N) develop affinity in terms of strong binding due to intrinsically dealing different nature of forces where non-conservative energy is being involved.

Ti metal is a transition metal, which remains grounded indicating the grounded format force where electrons of filled states remain attempting the gravitation behavior under the expansion of their clamping energy knots in a normal environment possessing ground point at below ground surface. On the other hand, a N atom belongs to gas behavior, which remains in the air indicating the space format force, which is being involved in keeping its ground point at above ground surface. The electrons of N atoms remain attempting the levitation behavior under contraction of clamping energy knots in their normal environment, thus, possessing ground point at above ground surface. Therefore, in their joint deposition under suitable coating technology unit, meant for this job, electrons of N atoms deal affinity in terms of dealing double clamping of unfilled energy knots of outer ring of Ti atoms. Double clamping of certain electrons of outer ring obey the natural behavior of binding as the atoms of N are searching for ground point at above ground surface while atoms of Ti are also searching for ground point but at below ground surface. While searching their ground points at different levels, they mutually get ready for the common ground point at the surface of depositing substrate. Under the tailored process parameters of their deposition at suitable substrate surface, they deal high adhesion and hard features of resulted coating where maximum number of two differently nature atoms stand for their ordered mid-points, thus, working as hard coating.

The electrons of N atoms deal double clamping of energy knots while focusing to unfilled states of Ti atoms where gas state atoms are uplifting while solid ones are grounding. Obviously, suitable gas state atoms deal double clamping of energy knot to their electrons when they deal the transition state, most probably, a re-crystallization state where approximate angle of electron with respect to clamping energy knot becomes ~ 35° at right-side of normal line in south-pole while attempting the levitation behavior under tickling of clamping energy knot. On approaching such aligned-angle electron of a N atom while forcefully grounding to energy knot of unfilled state of Ti atom uplifting forcefully results into deal double clamping of energy knot; one energy knot of electron belonging to its own and second energy knot (unfilled one) belonging to unfilled state of Ti atom. This double clamping of energy knot to electron of atom (N) grounding forcefully (at substrate surface) under unfilled state of clamping energy knot in Ti atom is shown in Figure 5. While attempting the gravitation behavior of gas atoms where clamping energy knots to electrons expand, the work is being done on the atoms. On the other hand, the work is being done by the atoms of solid behavior where clamping energy knots to electrons contract under levitation behavior. An atom of gas behavior with outer ring and an atom of solid behavior with outer ring are shown in Figure 5 at the instant of dealing double clamping of single electron which set the foundation of science behind hard coating.The inter-changeable force-energy paradigms discussed elsewhere [45] where in addition to describing structure of atoms of various elements, their origin to be in gas state (and to liquid) and to be in solid state (and to liquid) discussed also.

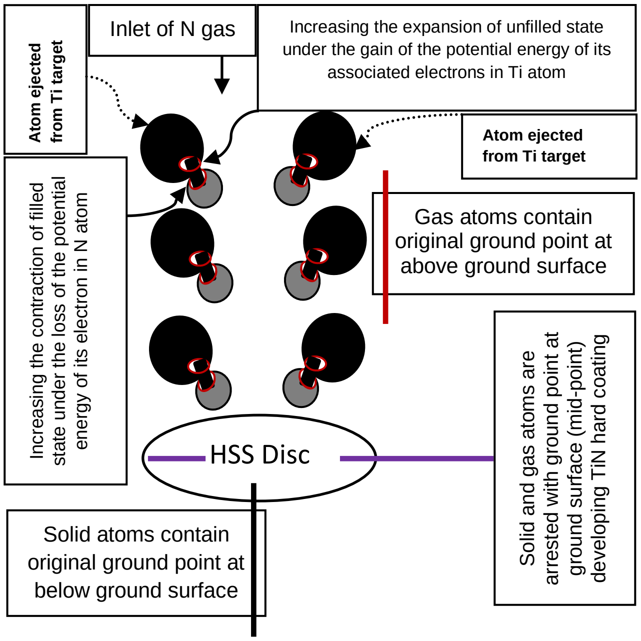

Figure 5: Mechanism of dealing double clamping of electron between two different (opposite force) ground points atoms developing structure of TiN hard coating

Because, solid atom is dealt with the tensing of force of surrounding environment, which is due to the buried ground point under the fully saturated behavior of its electrons in terms of gained potential energy as they deal gravitation behavior at maximum extent. Under conserved manner, nullified levitational force of occupied electrons for each of the transition state of atom releases the tension through dissipating energy, thus, attaining required amount of energy of different transition states of atom does self-work. The level of self-losing potential energy of electrons for each of state of their atom assigns the negative sign. Therefore, in atoms of solid, they do self-work which results into attain their respective states resulting into the contraction of their clamping energy knots having a fixed rate. Further detail is given elsewhere as it has been discussed that this is the contraction and expansion of clamping energy knots to electrons possessing mass (length) more than half at north-side and more than half at south-side determining gas behavior and solid behavior of their atoms, respectively [45]. Some of the detail while studying binding mechanism of different state carbon atoms is also given elsewhere [13] where bringing the gas state carbon atom into solid state carbon atom, the work is being done on that atom through providing the certain shape energy to its electrons. At this instant, the work done is positive. But in the case of a hard coating both solid atoms and gas atoms deal their opposite phenomena in the description. As, in one case, Ti atoms are reaching to substrate surface where it holds them in the form of deposition. In the second case, N atoms are entering in the middle space of ejecting Ti atoms through dealing the downward force where on instating their original ground point, which is at above ground surface, they are being arrested by the Ti atoms under the mechanism of dealing double clamping of electrons. Therefore, the work is being done by the N atoms as they were restoring their original state from certain transition state, which is under their self-work. Thus, the work done of N atoms remains negative. However, the work done of Ti atoms remains positive as they have gained energy to attain certain transition state where their ground point is not at below ground surface and they are waiting for attaining their ground point at below ground surface. While undertaking those transitions, Ti atoms present the unfilled states of outer rings to clamp suitable electrons of outer rings of N atoms, which are already in the clamp of their own energy knots, thus, formation of Ti-N deals mechanism of double clamping of energy knot to electron under accommodate level of their attained common ground point at just above ground surface or at ground surface of depositing substrate. The mechanism of double clamping of energy knot to electron dealing by many pairs of Ti-N atoms results into develop structure of high hardness as shown in Figure 5.

The similar sort of mechanisms is being anticipated in bi-metallic composition with gas behavior atoms, for example, TiAlN. Again, low measured-hardness coating of chromium nitride (compared to TiN) involves the same mechanism of binding their different nature atoms where high probability is involved as Cr atom contains many unfilled states of outer ring (compared to Ti atom). That's way CrN coating deals low surface roughness as compared to TiN coating [27] because of greater level of homogeneity of binding atoms in evolving their structure. A similar approach may be validated in exploring the science for other very hard, moderate hard and even less hard (soft and porous) coating materials. A different originating science mechanism may be anticipated in the case of TiCN hard coating where involving the same mechanism of double clamping of energy knot to possible electrons of two different metallic nature atoms. Arresting of gas state behavior atoms with metallic behavior atoms endorse the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 February 2018 doi:10.20944/preprints201802.0040.v1

behavior of force dealing by the electrons under the adjustment of expansion and contraction of clamping energy knots by gaining (increasing) and losing (decreasing) their potential energy, respectively.

4. Conclusions

This is the provision of solid atoms to deal double clamping of energy knots for electrons of gas atoms. The arresting of gas state atoms while the ground point is just at ground surface instead of the ground point at above ground surface decrease the force under the tensing behavior of electrons where their potential energy is being increased under the decrease of contraction of clamping energy knots. The arresting of metallic nature atoms while ground point is just at ground surface instead of ground point at below ground surface increase the force under relaxing behavior where their potential energy is being decreased under the increase of contraction of clamping energy knots. The increase in the expansion of energy knots clamping electrons of atoms of gas state and decrease in the expansion of energy knots clamping electrons of atoms of metallic state enable their affinity through which their developed structure works as a hard coating.

The underlying science of developing hard coating is that atoms of solid behavior deal work against their natural behavior where work done is positive as the atoms work at ground surface (substrate surface) while developing a structure of coating instead of having ground point at below ground surface, whereas, the work done is negative in the case of atoms of gas behavior as they hold ground point at ground surface (substrate surface) instead of at above ground surface while developing a structure of coating. In depositing hard coating, gas atoms engage gravitation behavior of electrons where the expansion of clamping energy knots takes place (on comparative grounds) while solid atoms engage levitation behavior of electrons where the contraction of clamping energy knots takes place (on comparative grounds). This results into deal double clamping of several available electrons of gas behavior atoms through several available unfilled states of solid behavior atoms under the accommodate level of their common ground points. This results into present the increasing of elastic behavior and the decreasing of plastic behavior along with other characteristics of the resulted hard coating.

Transition metals govern hard features of coating under their affinity to gas behavior atoms because, one is dealing the force of grounded format and other is dealing the force of space format resulting into locate the common ground point having mid-point at ground surface, which is between below ground surface and above ground surface. The electrons of gas atoms (N atoms) depositing on the substrate to evolve structure of TiN coating deal double clamping of energy knots of solid atoms having unoccupied electrons (Ti atoms) from the back side while attempting forcefully the gravitation behavior under their increased potential energy.

The behavior of gas atoms remains alive while arrested by solid behavior atoms. Appropriate vacuum conditions and high power enhance the hardness level of deposited coatings in the form of films. Hard coatings introduce certain properties and application due to the developing of their non-regular structure under non-conservative energy where non-conservative forces are involved. But, they are not overwhelming forever, and lifetime of hard coatings depends on their developing strategies along with the nature of usage. In line with this, deposition of hard coatings along with other ones requires the re-consideration in explaining the science of their structure formation.

Acknowledgements:

Mubarak Ali is obliged to Malaysian Government for awarding scholar of PhD study (2004-07) under award letter No. JPA(L) KD333487 and Government of Pakistan (MoST) for granting the study leave. He is also grateful to Malaysian colleagues at AMREC, SIRIM Berhad and at UTM Johor for their kind hospitality. Special thanks to Professor Dr. Ali Ourdjini for reviewing the work at several times and constructive feedback while studying at UTM who is now with the University of Ottawa, Canada.

References:

[1] M. Ali, Atoms of electronic transition deform or elongate but do not ionize while inert gas atoms split. http://arxiv.org/abs/1611.05392.

[2] M. Ali, Revealing the Phenomena of Heat and Photon Energy on Dealing Matter at Atomic level. https://www.preprints.org/manuscript/201701.0028/v10.

[3] M. Ali, Structure evolution in atoms of solid state dealing electron transitions. http://arxiv.org/abs/1611.01255.

[4] M. Ali, I –N. Lin, The effect of the Electronic Structure, Phase Transition, and Localized Dynamics of Atoms in the Formation of Tiny Particles of Gold. http://arxiv.org/abs/1604.07144.

[5] M. Ali, The study of tiny shaped particle dealing localized gravity at solution surface. http://arxiv.org/abs/1609.08047.

[6] M. Ali, Nanoparticles-Photons: Effective or Defective Nanomedicine, J. Nanomed. Res. 5 (6) (2017) 00139.

[7] M. Ali, I –N. Lin, Development of gold particles at varying precursor concentration. http://arXiv.org/abs/1604.07508.

[8] M. Ali, I –N. Lin, Controlling morphology-structure of particles at different pulse rate, polarity and effect of photons on structure. http://arxiv.org/abs/1605.04408.

[9] M. Ali, I –N. Lin, Formation of tiny particles and their extended shapes – Origin of physics and chemistry of materials. http://arxiv.org/abs/1605.09123.

[10] M. Ali, I –N. Lin, Tapping opportunity of tiny shaped particles and role of precursor in developing shaped particles. http://arxiv.org/abs/1605.02296.

[11] M. Ali, I –N. Lin, C. –J. Yeh, Predictor Packing in Developing Unprecedented Shaped Colloidal Particles. https://www.preprints.org/manuscript/201801.0039/v1

[12] M. Ali, I –N. Lin, Phase transitions and critical phenomena of tiny grains thin films synthesized in microwave plasma chemical vapor deposition and origin of v_1 peak. http://arXiv.org/abs/1604.07152.

[13] M. Ali, Atomic Structure and Binding of Carbon Atoms. (2018). https://www.preprints.org/manuscript/201801.0036/v1

[14] M. Ali, M. Ürgen, Switching dynamics of morphology-structure in chemically deposited carbon films –A new insight, Carbon 122 (2017) 653-663.

[15] M. Ali, M. Ürgen, Deposition Chamber Pressure on the Morphology of Carbon Films. (in submission process)

[16] M. Ali, E. Hamzah, M. R. M. Toff, A. H. Hashim, The effect of Nitrogen gas flow rate on the properties of TiN-coated HSS using Cathodic Arc Evaporation PVD Technique, Surf. Rev. Lett. 12 (2005) 631-643.

[17] M. Ali, E. Hamzah, M. R. M. Toff, Effect of metal ion etching on the tribological, mechanical and microstructural properties of TiN-coated D2 tool steel using CAE PVD technique, Surf. Rev. Lett. 13 (2006) 413-421.

[18] M. Ali, E. Hamzah, M. R. M. Toff, Effect of substrate bias voltage on the microstructural and mechanical properties of TiN-coated HSS synthesized by CAE PVD technique, Surf. Rev. Lett. 13 (2006) 621-633.

[19] E. Hamzah, M. Ali, M. R. M. Toff, Effect of substrate bias on friction coefficient, adhesion strength and hardness of TiN-coated D2 tool steel deposited via cathodic arc PVD technique, Surf. Rev. Lett. 13 (2006) 763-771.

[20] M. Ali, E. Hamzah, M. R. M. Toff, Deposition and characterizations of TiN-coated steels at various N_2 gas flow rates with constant etching by using cathodic arc physical vapour deposition technique, Surf. Rev. Lett. 14 (2007) 93-100.

[21] E. Hamzah, A. Ourdjini, M. Ali, P. Akhter, M. R. M. Toff, M. A. Hamid, Influence of nitrogen flow rate on friction coefficient and surface roughness of TiN coatings deposited on tool steel using arc method, Surf. Rev. Lett. 14 (2007) 1007-1013.

[22] M. Ali, P. Akhter, E. Hamzah, M. R. M. Toff, I. A. Qazi, Effect of coating thickness on the properties of TiN coatings deposited on tool steels using cathodic arc PVD technique, Surf. Rev. Lett. 15 (2008) 401-410.

[23] M. Ali, E. Hamzah, M. R. M. Toff, Friction coefficient and surface roughness of TiN-coated HSS deposited using cathodic arc evaporation PVD technique, Ind. Lubr. Tribol. 60 (2008) 121-130.

[24] M. Ali, E. Hamzah, T. Abbas, M. R. M. Toff, 1. A. Qazi, Macrodroplet reduction and growth mechanisms in cathodic arc physical vapour deposition of TiN films, Surf. Rev. Lett. 15 (2008) 653-659.

[25] M. Ali, E. Hamzah, N. Ali, Adhesion strength of TiN coatings at various ion etching deposited on tool steels using cathodic arc PVD technique, Surf. Rev. Lett. 16 (2009) 29-35.

[26] M. Ali, E. Hamzah, I. A. Qazi, M. R. M. Toff, Effect of Cathodic Arc PVD Parameters on Roughness of TiN Coating on Steel Substrate, Curr. Appl. Phys. 10 (2010) 471-474.

[27] M. Ali, E. Hamzah, M. R. M. Toff, Study of macrodroplet and growth mechanisms with and without ion etchings on the properties of TiN coatings deposited on HSS using cathodic arc physical vapour deposition technique, Mater. Sci. Eng. A 474 (2008) 236-242.

[28] H. Elmkhah, F. Attarzadeh, A. F. -alhosseini, K. H. Kim. Microstructural and electrochemical comparison between TiN coatings deposited through HIPIMS and DCMS techniques, J. Alloy. Compd. 735 (2018) 422-429.

[29] J.C. Oliveiraa, F. Fernandesa, R. Serraa, A. Cavaleiro. On the role of the energetic species in TiN thin film growth by reactive deep oscillation magnetron sputtering in Ar/N2, Thin Solid Films 645 (2018) 253-264.

[30] U. Vogel, S. Oswalda, J. Eckert. Interface and stability analysis of Tantalum- and Titanium nitride thin films onto Lithiumniobate, Appl. Surf. Sci. 425 (2017) 254-260.

[31] G. T. P. Azar, C. Yelkarasi, M. Ürgen. The role of droplets on the cavitation erosion damage of TiN coatings produced with cathodic arc physical vapor deposition, Surf. Coat. Technol. 322 (2017) 211-217.

[32] A. Bahri, E. Kaçar, S.S. Akkaya, K. Elleuch, M. Ürgen. Wear protection potential of TiN coatings for 304 stainless steels used in rotating parts during olive oil extraction, Surf. Coat. Technol. 304 (2016) 560-566.

[33] M.F. Othman, A.R. Bushroa & W.N.R. Abdullah. Evaluation techniques and improvements of adhesion strength for TiN coating in tool applications: a review, J. Adhes. Sci. Technol., 29 (2015) 569-591.

[34] Q.W. Jiang, G.R. Li, X.P. Gao, Highly ordered TiN nanotube arrays as counter electrodes for dye-sensitized solar cells, Chem. Commun. 44 (2009) 6720-6722.

[35] S.G. Harris, E.D. Doyle, Y.-C. Wong, P.R. Munroe, J.M. Cairney, J.M. Long. Reducing the macroparticle content of cathodic arc evaporated TiN coatings, Surf. Coat. Technol., 183 (2004) 283-294.

[36] L. von Fieandta, K. Johanssona, T. Larssonb, M. Bomana, E. Lindahlc. On the growth, orientation and hardness of chemical vapor deposited Ti(C,N), Thin Solid Films 645 (2018) 19-26.

[37] K. Bobzin, High-performance coatings for cutting tools, CIRP Jour. Manuf. Sci. Technol., 18 (2017) 1-9.

[38] Q. Wang, F. Zhou. Progress in Tribological Properties of Nano-Composite Hard Coatings under Water Lubrication, Lubricants 5 (2017) 5

[39] D. Music, R. W. Geyer, J. M. Schneider. Recent progress and new directions in density functional theory based design of hard coatings, Surf. Coat. Technol. 286 (2016) 178-190.

[40] E. Santecchiaa, A.M.S. Hamoudaa, F. Musharavatia, E. Zalnezhadb, M. Cabibboc, S. Spigarellic, Wear resistance investigation of titanium nitride-based coatings, Ceram. Int. 41 (2015) 10349-10379.

[41] Y. X. Wang, S. Zhang. Toward hard yet tough ceramic coatings, Surf. Coat. Technol. 258 (2014) 1-16.

[42] A. Inspektor, P. A. Salvador. Architecture of PVD coatings for metalcutting applications: A review, Surf. Coat. Technol. 257 (2014) 138-153.

[43] A. D. Pogrebnjaka, A. V. Pshyka, V. M. Beresnevb, B. R. Zhollybekova. Protection of specimens against friction and wear using titanium-based multicomponent nanocomposite coatings: A review, J. Frict. Wear, 35 (2014) 55-66.

[44] M. Fenker, M. Balzer, H. Kappl. Corrosion protection with hard coatings on steel: Past approaches and current research efforts, Surf. Coat. Technol., 257 (2014) 182-205.

[45] Y. Purandarea, A. Ehiasarian, A. Santana, P. Hovsepian. ZrN coatings deposited by high power impulse magnetron sputtering and cathodic arc techniques, J. Vac. Sci. Technol. A, 32 (2014) 031507.

[46] C. Mitterer, F. Holler, F. Üstel, D. Heim. Application of hard coatings in aluminium die casting -soldering, erosion and thermal fatigue behaviour, Surf. Coat. Technol., 125 (2000) 233-239.

[47] W.-D. Münz, T. Hurkmans, G. Keiren, T. Trinh. Comparison of TiAlN coatings grown by unbalanced magnetron and arc bond sputtering techniques, J. Vac. Sci. Technol. A, 11 (1993) 2583-2589.

[48] S.C. Glotzer, M.J. Solomon, Anisotropy of building blocks and their assembly into complex structures, Nature Mater. 6 (2007) 557-562.

[49] S. Link, M.A. El-Sayed, Shape and size dependence of radiative, nonradiative and photothermal properties of gold nanocrystals, Int. Rev. Phys. Chem. 19 (2000) 409- 453.

[50] M. Ali. Why atoms of some elements are in gas state and some in solid state, but carbon works on either side (2018). (in submission process)

Authors' biography:

Mubarak Ali graduated from University of the Punjab with B.Sc. (Phys& Maths) in 1996 and M.Sc. Materials Science with distinction at Bahauddin Zakariya University, Multan, Pakistan (1998); thesis work completed at Quaid-i-Azam University Islamabad. He gained Ph.D. in Mechanical Engineering from Universiti Teknologi Malaysia under the award of Malaysian Technical Cooperation Programme (MTCP;2004-07) and postdoc in advanced surface technologies at Istanbul Technical University under the foreign fellowship of The Scientific and Technological Research Council of Turkey (TÜBİTAK; 2010). He completed another postdoc in the field of nanotechnology at Tamkang University Taipei (2013-2014) sponsored by National Science Council now M/o Science and Technology, Taiwan (R.O.C.). Presently, he is working as Assistant Professor on tenure track at COMSATS Institute of Information Technology, Islamabad campus, Pakistan (since May 2008) and prior to that worked as assistant director/deputy director at M/o Science & Technology (Pakistan Council of Renewable Energy Technologies, Islamabad; 2000-2008). He was invited by Institute for Materials Research (IMR), Tohoku University, Japan to deliver scientific talk on growth of synthetic diamond without seeding treatment and synthesis of tantalum carbide. He gave several scientific talks in various countries. His core area of research includes materials science, physics & nanotechnology. He was also offered the merit scholarship (for PhD study) by the Government of Pakistan but he couldn't avail. He is author of several articles published in various periodicals (https://scholar.google.com.pk/citations?hl=en&user=UYjvhDwAAAAJ).

Dr Esah Hamzah is a senior standing Professor at Universiti Teknologi Malaysia in the Faculty of Mechanical Engineering. Dr Esah obtained her BSc degree from the University of Wales at Swansea, UK, and MSc and PhD in Metallurgy from the University of Manchester Institute of Science and Technology (U.M.I.S.T.) UK. She has over 30 years of experience in teaching the undergraduate and postgraduate courses related to metallurgy and materials engineering. She has also supervised both masters and PhD students and has served as an examiner for MSc and PhD theses. She has held various administrative positions at the Universiti Teknologi Malaysia and remained Head of Department (1999-2005) and Deputy Dean (Academics) of the Faculty of Mechanical Engineering (2005-2010). She has been actively involved in research namely in the areas of phase transformation and mechanical behavior of metals, metal failure, corrosion and coating. She has been awarded many research grants from the University and the Malaysian Government. She has also presented and published more than 200 papers in the national and international conferences and journals. Some of her papers won the "Best Paper" award at various International events. She is also a contributor to the University's Best Publication Award won by the Faculty of Mechanical Engineering in series of years along with Excellent Service for the year 1993 and the University Excellence Award in 2000, 2003 and 2007. Dr Esah is an active Council Member, charted engineer, and in pioneering Fellow members of the Institute of Materials Malaysia (IMM).

Dr. Mohd Radzi Mohd Toff is a General Manager at Advanced Materials Research Centre (AMREC), SIRIM BHD, Malaysia and prior to that worked as head of coating technology group at AMREC and principal scientist. He graduated from Universiti Kebangsaan Malaysian (UKM) and earned PhD in Chemical Engineering from The University of sheffield, UK.