Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

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 University Islamabad, Park Road, Islamabad-45550, PAKISTAN, *E-mail: mubarak74@mail.com or mubarak74@comsats.edu.pk

[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 suitable materials having thickness of few atoms to several microns on a substrate have caught the regular attention of scientific community working in various fields of science and technology. Decorative and protective coatings, transparent and insulating coatings, coatings of medical implants and surgical instruments, coatings for drug delivery, ultra-precision machine-tool coatings and coatings for miscellaneous uses are in the routine demand. Different hard coatings develop under the significant composition of suitably different natured atoms where their force-energy behaviors, when in their certain transition states, provide the provision to bind (adhere). In the binding mechanism of different nature suitable atoms, electron (of outer ring) belonging to filled state gaseous nature atom takes another clamp of energy knot (of outer ring) belonging to unfilled state solid-natured atom. Set conditions of the process provide the provision of binding different nature atoms in a technique or method meant for it. Different natures of atoms develop structure in the form of hard coating by locating ground points between their original ones where gaseous nature atoms increase potential energy under the decreasing levitational force at electron-level while the solid atoms decrease potential energy under the decreasing gravitational force at

electron-level. Ti–Ti binding occurs through the difference of expansion of their energy knots nets when one atom just lands on the already landed atom while the adhered nitrogen atom incorporates at their interstitial position. Under suitable set parameters, differently natured atoms deposit in the form of coating at substrate surface under the given conditions. The rate of solid-natured atoms ejecting or dissociating from the source depend on its nature, process parameters and the processing technique or approach. In random arc-based vapor deposition system, depositing differently natured atoms at substrate surface depends on the input power. In addition to intrinsic nature of atoms, different properties and characteristics of coatings emerge as per engaged forces under the involved energy. The present study sets new trends in the field of coatings involving the diversified class of materials and their counterparts.

Keywords: Fundamental science; Atomic behavior; Hard coating; Expansion and contraction; Force-energy behaviors; Surface and interface

1. Introduction

Hard coatings are the integral part of scientific research and technological advances. In market, hard coatings for different purposes are in routine use where their ingredients and deposition techniques are the hot topics. In this context, several materials involving different atoms and deposition techniques are available in the literature, discussing and explaining their deposition history along with the features of substrate material. In coatings, a minute quantity of deposited materials (in the form of coating) over less-important or not practically viable material gives the value-added benefits.

A variety of techniques are involved in depositing different sorts of hard coatings at the surface of suitable substrates. Coatings are mainly used for two reasons; firstly, the potential use of coated part and secondly, for their substitution. Overall, coating the surface of a certain substrate results into its different behavior of functioning, often in an astonishing way.

Solid-natured atoms of unfilled states do not elongate and those belonging to inert gases split under the excess propagation of photons characteristic current [1]. A neutral state silicon atom transforms heat energy into photon energy [2]. Atoms of suitable solid

 doi:10.20944/preprints201802.0040.v7

behavior evolve structures of different dimension and format as per the nature of built-in electronic gauge where conservative forces are applied (involved) to execute their confined inter-state electron-dynamics [3]. Why the origins of atoms in some elements are in gas states and in some elements in solid states are discussed [4]. A gas state carbon atom originates several different states, which are under the involvement of typical energy, providing the path for filled state electron to migrate into nearby unfilled state [5]. Different natures of atoms for their tiny-sized particles play different role in originating the application, which can be effective or defective for their application point of view [6].

Developing different hierarchical tiny particles under varying conditions of the process is due to different attained dynamics of amalgamated atoms [7]. A monolayer triangular-shaped tiny particle is considered as the model system, discussing the elongation behavior of atoms belonging to its 1D arrays where converted structures of smooth elements further shape under the influence of travelling photons along their interface [8]. At suitable precursor concentration, many tiny particles shape-like equilateral triangle are developed [9]. Shapes of tiny-sized particles and large-sized particles are controlled under the application of different ratios of pulse OFF to ON time [10]. Particles of different shapes are developed in less than millisecond time while processing gold precursor in pulse-based electron-photon solution-interface process [11]. Developing different tiny-sized particles was discussed when different precursors were processed [12]. Predictor packing while developing geometric anisotropic gold particles was envisaged [13], where controlled force-energy behaviors regulate the shape.

Different behaviors of tiny grains carbon films registered under Raman spectroscopy and energy loss spectroscopy indicated several phases of tiny grains [14]. Switching morphology-structure of grains and crystallites under a bit altered locally operating parameters in developing carbon films is discussed elsewhere [15]. Under varying chamber pressure, a discernible change in the morphology and growth rate of carbon films was observed [16].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

While depositing TiN coatings on different substrates under varying process conditions employing 'cathodic arc physical vapor deposition', a different morphology-structure along with hardness, surface roughness, friction coefficient, adhesion strength and overall performance of coated tools have been studied [17-28]. In addition to these studies, there are several other available studies in the literature targeting TiN coatings along with their processing techniques and analyses [29-36]. In addition to TiN coating, different types of hard coatings developed under various conditions have also been published extensively [37-48]. The basic idea discussed in those studies is related to the properties and characteristic of deposited coatings, which are subjected mainly to the change of process parameters, types of material and processing approach.

The prosperous assembling of colloidal matter into meaningful structure will result into treat atoms and molecules tomorrow's materials [49] and understanding in the individual dynamics of tiny sized particles formation is essential before enabling their assembling to the useful large sized particles [50].

In addition to the discussed scientific details available for hard coatings, coatings are in the way to express relation between comprised atoms. This study reports the fundamental aspects of developing hard coatings with special emphasis on depositing TiN coating on a high-speed steel (HSS) disc while employing random arc-based vapor deposition technique. This work presents the fundamental aspects of depositing hard coating, in general, and investigating mechanism of developing TiN coating, in specific.

2. Experimental details

HSS discs were utilized as a substrate material for the deposition of TiN while employing the commercially available coating unit known as 'cathodic arc physical vapor deposition technique', which is now termed as 'random arc-based vapor deposition technique' in the present study. After the required cleaning, the samples having diameter: 10 mm and 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 in the earlier work [28]. Surface and interface cross-sectional views were captured by using field emission

scanning microscope (FESM known as FE-SEM, Model LEO-1525). The thickness of the deposited coatings was measured under the application of field emission scanning microscope and through the captured fractured cross-sectional image of the deposited coating on HSS substrate. Prior to coat (deposit) TiN on treated HSS disc, an inter-layer of Ti-atoms was deposited for the period of 15 min process time. The purpose of depositing inter-layer was to enhance the adhesion strength of the following TiN coating. So, instead of nitrogen gas, an inert argon gas was regulated through mass flow controller to incorporate into the deposition chamber to ignite the arc. At the start of depositing inter-layer, chamber pressure was 5×10^{-6} mbar. While depositing inter-layer, 50 sccm nitrogen gas flow rate was maintained by mass flow controller meter. To deposit TiN in the form of coating, substrate temperature was 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 controlled as given elsewhere [28]. Input current for igniting arc to eject Ti-atoms from the target was 100 A. Total duration of the deposition process was set at 90 min.

3. Results and discussion

Figure 1 (a) shows surface topography of deposited TiN coating on HSS disc where the surface is partially covered with macrodroplets (MDs), size ranging from few hundred of nanometers to few microns. The distribution of MDs is uniform throughout the surface of deposited coating. A large sized macrodroplet (MD) in the central vicinity of deposited coating shown in Figure 1 (a) shows mapping of the region where the concentration of both Ti and N atoms is shown in different colors. Figure 1 (b) shows fractured cross-sectional view of the coating where initially deposited Ti inter-layer shows thickness less than one micron. Atoms of Ti inter-layer adhere to substrate under its favorable conditions and different texture of few nanometers thick deposited layer between the substrate and deposited TiN coating is apparent in Figure 1 (b).

Substrate surface comprising different elements like W, Mo, Cr, V, C and Fe adhered to Ti-atoms at initial stage can improve the adhesion of the afterward deposited coating [17, 24]. Ti-atoms bind to the substrate surface under suitable conditions of the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

depositing inter-layer. The nature of substrate surface comprised atoms of different natures where certain captured force-energy trends enable their binding to the depositing few nanometers thick Ti-atoms layer. This inter-layer workout for the adhesion strength of afterward depositing coatings needs to be investigated further. Some preliminary detail regrading adhesion strength of TiN coating deposited under certain conditions in random arc-based vapor deposition system is discussed elsewhere [26, 28].

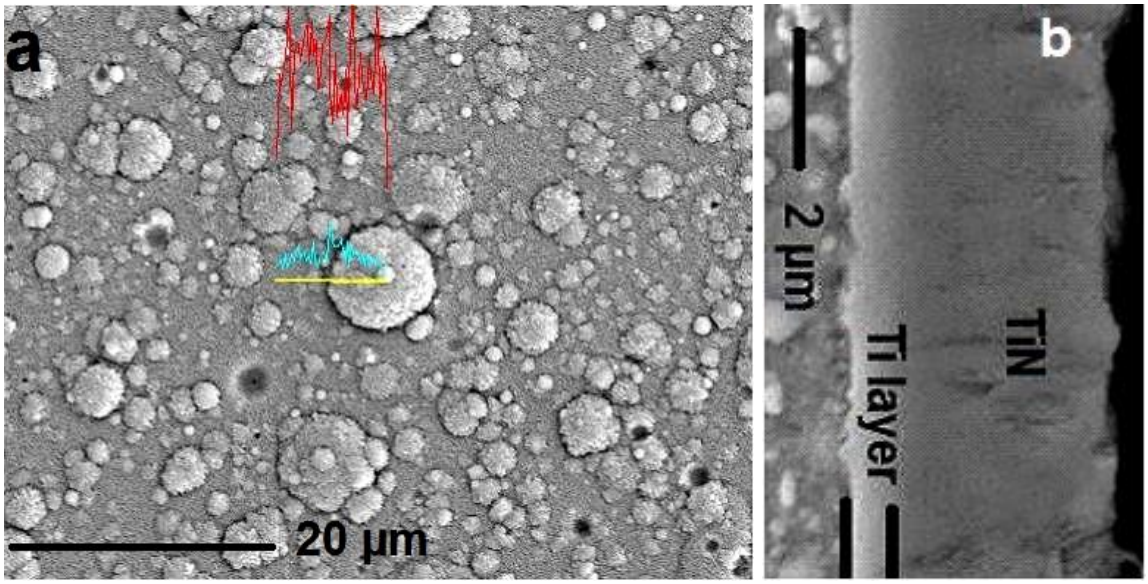


Figure 1: *(a) topographic view of TiN coating on HSS disc and (b) few hundred nanometers thick titanium inter-layer shows contrast with respect to afterward deposited TiN coating having thickness ~4 µm*

Figure 2 shows the mapping of Ti-atoms found in the deposited TiN coating at the point of its MD (in Figure 1a) in the form of histogram where its content is around 70%. This indicates that the portion of coating covered by Ti-atoms in top front surface coating not only contained 70% of its content, but the distribution of Ti-atoms in MD also remained uniform. This indicates that MD contained less concentration of N-atoms.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

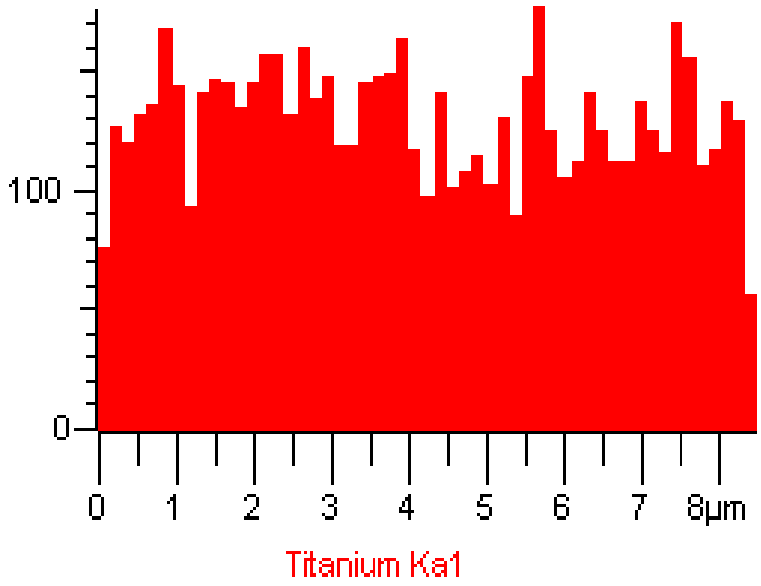


Figure 2: *Mapping of Ti-atoms distribution along with the ratio of content*

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

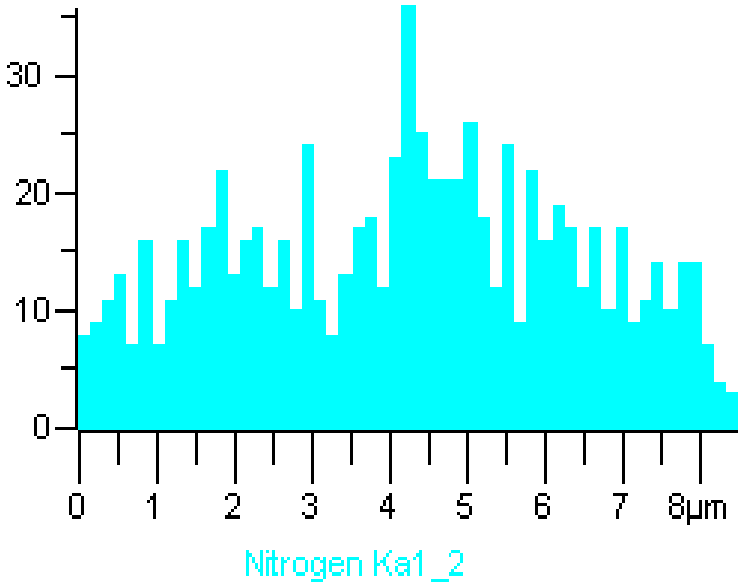


Figure 3: *Mapping of N-atoms distribution along with the ratio of content*

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

There are several studies where reduction of MDs for depositing hard coatings was investigated under the different conditions of process along with impact of their tools in the ultra-precision machining [17-20, 23-25].

Hard coatings belong to the category of refractory materials. They don't conduct field despite of the fact that their major component contains atoms of metallic nature. Adherence of gaseous atoms to metallic atoms result in the formation of coatings with low conductivity and gaseous atoms act as insulator, where field of propagating photons (having characteristic of current) is interrupted to a large extent. This is because of locking inter-state electron gaps for metallic nature atoms by means of incorporating gas-natured atoms. This results into a development of disorder in the structure of the resulted coating. In the case of disordered structure, it is only within the short-range order. The incorporated N-atoms built the bridges *via* their certain electrons where they undertake another clamp of unfilled energy knot belonging to outer rings of Ti-atoms. This results into lowering the propagation of photonic current known as electric or electronic current also. A detailed study by Ali [1] has discussed the significance of inter-state electron gaps in atoms of different elements; propagation of photonic current (or photons having wavelengths other than that of current) requires no more the band gap between conduction band and valence band. This indicates that science of semiconductor materials or other types of materials require new and fresh thoughts to explain the origin of their different hidden phenomena.

In random arc-based vapor deposition system, atoms of Ti (or other metallic atoms) are ejected from the front-surface of their targets where arc (in different shape) is utilized to eject atoms under the supply of high energy. At high concentration of N-atoms, a random arc is steered to eject Ti-atoms both in atomic form and tiny-sized cluster (droplet) depending on the nature of Ti targets along with employed conditions of vapor deposition process. The basic layout of ejecting Ti-atoms and entering N-atoms to deposit TiN coating is sketched in estimation (Figure 4).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

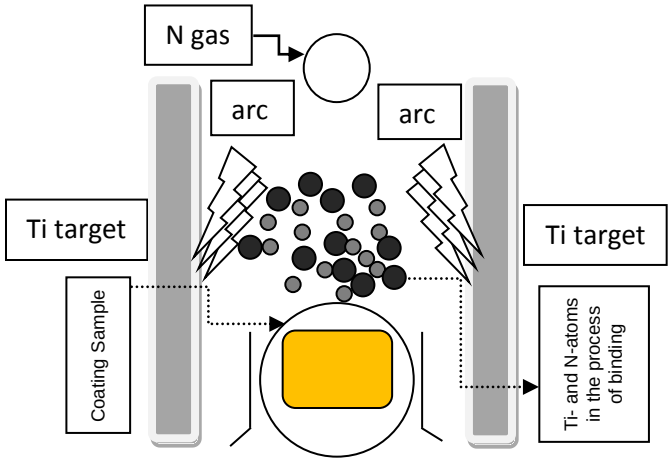


Figure 4: *The basic layout of depositing Ti-atoms and N-atoms to develop TiN coating at the surface of HSS substrate*

A newly observed atomic structure for atoms of Ti and N elements is shown in Figure 5. The tinniest sized particles called (named) electrons are filled (arrested) in the hollow space formed by the inter-crossed overt photons (with understanding of filled/unfilled states) under their certain symmetry where wavelength of those (overt) photons is in the current (conventionally known as electric or electronic current). A detailed study has discussed the atomic structure of atoms belonging to different elements along with origins of their different states [4]. A separate study has discussed the lattice (energy knot net) and atomic structure of different state carbon atoms [5]. In the case where electrons don't fill the inter-crossed regions of energy knots (hollow space), they are related to (termed as) the unfilled states for those atoms. For Ti-atom, total 32 states of electrons are available, but 24 states are filled by the electrons while 8 states are remained unfilled. In the case of inner unfilled states of the atom, they are being remained pressed by the covered filled states as indicated in Figure 5. Both filled and unfilled states of Ti-atom are formed (constructed) by the inter-crossed overt photons having their dedicated length. The required numbers of overt photons are being inter-crossed with understanding of filled and unfilled states for their atoms of each element. The wavelength of each inter-crossed overt photon to form the 'energy knot net' of an atom is in the inter-state electron where their lengths are as per the number of electrons (along with unfilled states) it owns. A detailed study has discussed different types of photons and nature of the overt photons [2]. Similarly, the atomic structures

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

along with their behaviors were discussed in a separate study [4]. However, unfilled states belonging to outer ring, where electrons don't occupy the position at the terminals of certain chain of states are shown in Figure 5.

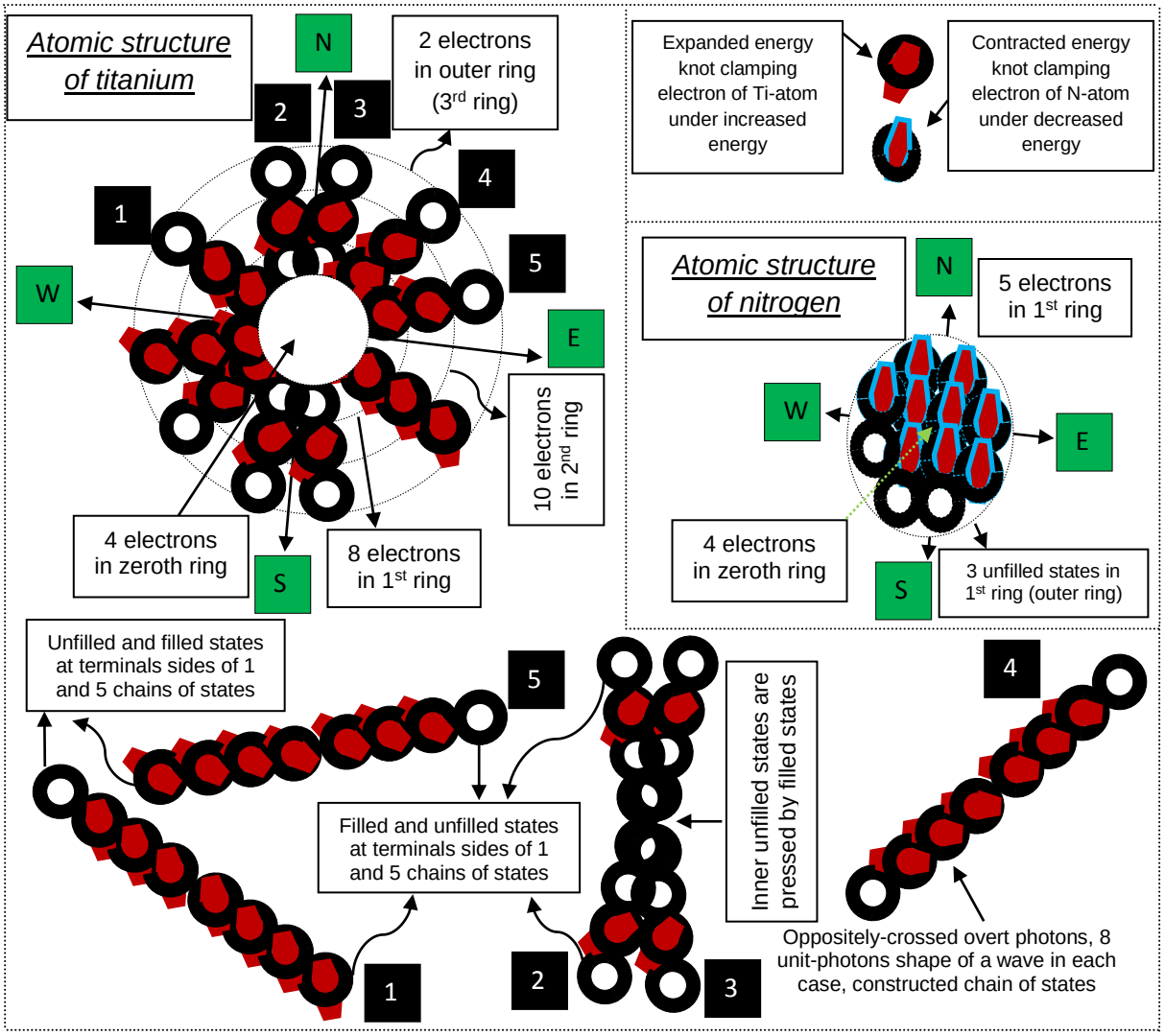


Figure 5: *newly observed atomic structure of atoms belonging to Ti and N elements; involved different chain of states are shown at bottom indicating filled, unfilled states and pressed (unused) states for Ti-atom*

Two overt photons comprising length of eight unit-photons cross while travelling to opposite direction construct a chain of filled and unfilled states of electrons. As shown in the bottom part of Figure 5 where five such shapes are drawn and their precise inter-crossing at a common center to form the 'energy knot net' of Ti-atom with 24 filled

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

states. Expanded and contracted energy knots (in estimation) clamping electrons in Ti-atom and N-atom, respectively, are also shown in Figure 5. Filled states of outer ring in the atoms of solid and gas donate the positive valency and negative valency respectively. For the case of Ti atom, valency is +2, so, it has '8' unfilled states. In the case of nitrogen atom, valency is -3, so, it has '5' unfilled states. Hence, negative sign of valency in gas-natured atoms indicates their ground point at above average-leveled ground surface and positive sign of valency in solid-natured atoms indicates their ground points at below average-leveled ground surface. Inner four electrons of atoms belonging to each element form the zeroth ring, whereas, others are related to the available consecutive rings [4].

In different coating technology units, regardless of that the required numbers of atoms per unit area or volume are deposited under set parameters of the process, their involved energy is based on individually attained dynamics plus electron-dynamics, which is the key to regulate their structure, and so, there is emergence of properties and characteristics of their coating. However, it appears that evolving structure of TiN coating in the order of certain homogeneity is within the short-range order. Therefore, the deposited coating is developed mainly under the mixed behavior of structure evolution. Each Ti-atom only holds two electrons in the outer ring. This low number of filled states enables it to occupy many unfilled states of outer ring. Being a solid-natured atom, it should possess unfilled states at above east-west poles, both at left and right sides of the north-pole. As the Ti element belongs to grounded format, so, electrons of filled states (of outer ring) in atoms remain at below east-west poles along the south-pole. On the other hand, five filled states in outer ring of N-atom allow a smaller number of unfilled states in the outer ring. Due to the gas nature of N-atom, it contains several filled states of outer ring where majority of the electrons (filled states) are expected to be at above the east-west poles along the north-pole in each dedicated state. Further details of the origin of gas-natured atoms belonging to some elements have been discussed in a separate study [4]. The availability of several unfilled states of outer ring in Ti-atom provides provision to function for electrons of filled states of outer ring in N-atom where targeted electron (of gas-natured atom) is being clamped by another

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

unfilled energy knot of solid-natured atom. The double-clamping of energy knot to the electron of N-atom is by means of energy knot clamping unfilled state of outer ring in the Ti-atom. The mechanism of double clamping of energy knot by the electron is by means of suitable transition state in gas- and solid-natured atoms. Atoms in a certain transition state adjust potential energy of their electrons as per exertion of orientationally-controlled force [4]. Therefore, two different nature atoms (Ti and N) develop affinity in terms of strong binding.

A metallic target is developed under the solidification of transition state atoms, most probably, when they are under their re-crystallization transition state. The processed ore of metallic target is at the level of ground surface but their atoms in original solid state are to be at the below level to ground surface. Similarly, gas-natured atoms compressed in the container are in the re-crystallization transition state as well at the level of ground surface, whereas, they are in original gas state at the above level to ground surface. On ejection of solid-natured atoms from the target and flowing of the compressed gas-natured atoms from the container, they are again in transition to restore their original states. So, in the attempt of reviving their original state behaviours, they react (fast interact) just at above the substrate of their deposition. At instant of their reaction (fast interaction), different natured atoms are in their nearly opposite switched force-energy behaviours. Here, under their suitable interactions, electrons of gas-natured atoms enter to unfilled states of solid-natured atoms. In both cases, entering electrons of filled states and clamping energy knots of unfilled states, they belong to the outer ring of their atoms. When gas-natured atoms are in the re-crystallization state, their electrons go downward under infinitesimal displacements where they decrease their levitational force by gaining potential energy. But, electrons of the gas-natured atoms are still more than 50% to upward at mid of their clamped energy knots. When solid-natured atoms are in the re-crystallization state, their electrons go upward under infinitesimal displacements where they decrease their gravitational force by losing the potential energy. But, electrons of the solid-natured atoms are still more than 50% to downward direction at mid of their clamped energy knots. When different natured atoms reach their suitable transition states, a certain electron of the gas-natured atom undertakes another clamp

of certain energy knot belonging to solid-natured atom. When gas- and solid-natured atoms attain their suitable transition states where electron of a gas-natured atom experiences exerting (or applying) force to its north-sided tip from unfilled energy knot of solid-natured, they undertake the binding to adhere. Thus, that electron undertakes another clamp of energy knot in addition to its own. This mechanism of undertaking double clamping of certain electron by certain unfilled energy knot in different natured atoms is under their certain transitions states and when attempting to restore original state behaviors. When many such different natured atoms per unit area negotiate the same scheme of adherence, they develop nearly unchanging hard features of their coatings.

Atoms of metallic targets are already in contraction of energy knots clamped electrons and unfilled states as they are not in their original solid behavior. On the other hand, entered gas-natured atoms to the chamber are in the expansion of energy knots clamping electrons because, they are at ground surface now instead of being at above the ground surface. Therefore, different natured atoms switch force-energy behaviors nearly in opposite manner. Just at instant of recovering their original behaviors, they bind under suitable coordination where targeted electron of gas-natured atom undertakes another clamp of targeted unfilled energy knot of solid-natured atom. Therefore, solid-natured (Ti) atoms have already done work negatively (arriving near to ground surface from the south-side) while gas-natured (N) atoms have already done work positively (arriving near to ground surface from the north-side). To recover the state behaviors of two differently natured atoms to be in suitable transition states, they switch their force-energy behaviors, where work done by the gas-natured atom is negative while work done by the solid-natured atom is positive. So, they react to undertake double clamping of the suitable electron of the N-atom through suitable unfilled state of the Ti-atom.

Ti is known to have metallic character where filled state electrons of atoms deal their maximum gravitational force, so, they also possess the maximum expansion of their clamped energy knots. Thus, electrons of Ti-atoms keep the original ground point at below ground surface under original solid state. A N-atom belongs to gaseous state and

 doi:10.20944/preprints201802.0040.v7

it remains at above average-leveled ground surface where its electrons deal the maximum levitational force. So, electrons of N-atom possess the maximum contraction of their clamped energy knots. Therefore, in their deposition while employing a suitable coating technology unit, electron of outer ring belonging to N-atom clamp by another energy knot clamping to unfilled state of outer ring in Ti-atom. Given conditions of the process enables another clamping of the energy knot (belonging to Ti-atom) to a suitable filled state electron of the N-atom where energy is involved to engage the force. This results into attaining their ground point neither at above ground surface nor at below ground surface. So, they attain their common ground point at above or just at the surface of depositing substrate. Under the tailored process parameters of deposition, structure of hard coating exhibits high hardness because of the maximum ordering of different nature transition state atoms where their attained mid-points remain ordered to a large extent.

The electrons of N-atoms undertake double clamps of energy knots while visualizing through unfilled states of Ti-atoms where gas state atoms are being uplifted while solid ones are being grounded. Suitable transition state atoms undertake double clamps of targeted energy knots (belonging to solid-natured atoms) to targeted electrons (belonging to gas-natured atoms) under their favorable coinciding. The mechanism of double clamping of suitable energy knots to suitable electrons of N-atoms is grounded forcefully by the Ti-atoms (through suitable energy knots clamping unfilled states) as shown in Figure 6. Binding of Ti-atom to Ti-atom under the application of an electron (belonging to the just landed less expanded Ti-atom) to undertake another (double) clamp of energy knot (belonging to the already landed more expanded Ti-atom) is also shown in Figure 6 where N-atoms mainly position at interstitial sites of Ti-atoms. Under the action of tailored force-energy behaviors of N-atoms and Ti-atoms, they react, which results into their adhesion to develop TiN coating at surface of the substrate. Solid-natured atoms in original state behavior kept orientational gravitational force to the maximum extent, which is due to their grounded ground points being under fully gravitized behavior at electron-levels, thus, their electrons gain the maximum potential energy where clamped energy knots are remained in their maximum expansion. So,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

energy knots constructing unfilled states in those atoms also expand maximally. But, gas-natured atoms when in original state behaviors keep their orientational levitational force to the minimum, which is due to their ground points being above the ground surface under fully levitized behavior at electron-levels. Therefore, their electrons gain the minimum potential energy where clamped energy knots are in their maximum contraction. So, those energy knots related to unfilled states in gaseous state atoms also remain in their maximum level of contraction.

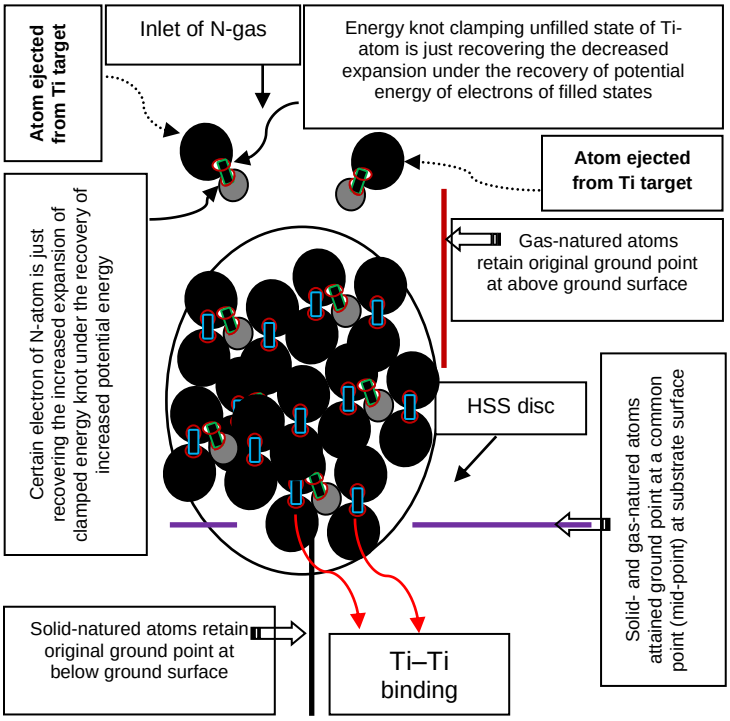


Figure 6: *Mechanism of double clamping of suitable energy knots to suitable electrons of gas-natured atoms through suitable energy knots clamping unfilled states of solid-natured atoms along with Ti–Ti binding*

When a Ti-atom lands at substrate, it recovers its transition state into original solid behavior where electrons start to gravitize. However, prior to being fully gravitized, an adequate expansion of the 'energy knots net' under increased (gained) potential energy takes place. Whereas, after landing, Ti-atom attains ground point at the surface of previously landed atom due to the less expansion of net of energy knots. Therefore, a certain electron of less expanded landed Ti-atom (where it is pointing toward the

downward-side) enters to a suitable vacant energy knot of a more expanded landed Ti-atom (where it is pointing toward the upward-side). This results into binding the two identical atoms. Now, forcefully grounded nitrogen atoms tend to recover state to go into original gas behavior where their certain electrons are entered to certain vacant energy knots of Ti-atoms from the back-side (rearward-side). In this way, nitrogen atoms are trapped at interstitial position of the Ti-atoms. Binding of nitrogen atoms at interstitial positions of bound Ti-atoms is also shown in Figure 6. Atoms of N (or other suitable gas elements) and Ti (or other suitable solid elements) engage energy under the exerting forces of fixed poles of electrons when they are in their original states. But the situation becomes different when they undertake certain transition (liquid) state where, in the solid-natured atoms, energy is directly proportional to the force (gravitational) exerting at electron-level, whereas, in the gas-natured atoms, energy is inversely proportional to the force (levitational) exerting at electron-level. Further details of energy-force (or force-energy) relationships in the case of gas-natured atoms and solid-natured atoms are given elsewhere [4].

The similar sort of mechanism 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 mechanism of binding their different nature atoms under similar lines where high probability of binding is involved as Cr-atom contains many unfilled states in the outer ring (compared to Ti-atom), leading to low surface roughness of CrN coating when compared to TiN coating [28]. In addition, greater level of homogeneity of binding atoms while evolving structure also influence the surface roughness. A similar approach may be validated to explore the science of other hard, moderate hard and even less hard (soft and porous) coating materials. A different originating scientific mechanism may be anticipated in the case of TiCN coating because of involving the carbon atoms, which requires additional lines to express the science. Reaction of gas- and solid-natured atoms endorse engaging of force exerting by their electrons under the adjustment of expansion and contraction of clamped energy knots, respectively. In this case, the energy is being involved. Developing hard coating is related to non-conserved energy where non-conservative (frictional) forces are

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

engaged to sustain the structure of coating. However, where the force element is involved first, the energy is being engaged as for the case of silicon atoms [2]; conservative forces are involved to configure the energy in the form of forcing energy (photon) where a photon wavelength having characteristic of current [1] and different types photons [2] is discussed. Overt-photons of different lengths having different numbers are being used to construct unfilled and filled states of electrons describing the origins of atoms belonging to different elements of periodic table [4] and conversion of a gaseous state carbon atom into any of its state involves the 'energy knots net' of inter-crossed overt-photons of same length and same number [5].

When solid-natured atom is just recovering from the transition state, it allocates certain unfilled energy knot belonging to outer ring to take another clamp for certain filled state electron of gaseous nature atom, which is also recovering from the certain transition state. The reaction of gas-natured atom while in ground point is just at ground surface (instead of at above ground surface) because of increased orientating gravitational force of its electrons where their potential energy is increased resulting into increase the expansion of clamped energy knots. The reaction of metallic atom when the ground point is just at ground surface (instead of at below ground surface) occurs because of decreased orientating gravitational force of its electrons where their potential energy is decreased, causing the expansion of clamped energy knots to decrease as well. This results into the binding of different natured atoms at a common ground point. The common ground point is at the mid of ground points of gas- and solid-natured atoms when in original state behavior, thus, engage force as per their involved energy to work as a hard coating.

Certain transition metals govern hard features of coating under affinity to gas-natured atoms because, one is undertaking the force of grounded format and other is undertaking the force of space format resulting into locate their common ground points having mid-points at the level of ground surface. The electron of outer ring belonging to gas-natured atom (N-atom) reacts to develop CrN by having another clamp of energy knot clamped by the unfilled state of outer ring belonging to solid-natured atom (Cr-atom). At the time of recovering transition state of Cr-atoms, they are just at the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

substrate surface, thus, they react with N-atoms, which are also just at substrate surface at the instant of recovering transition state. Cr-atoms just on landing undertake less expansion of their 'energy knots nets' than the 'energy knots nets' of already landed Cr-atoms, resulting into devise the unit (primitive) cell of hard coating as well when under their appropriate coinciding where N-atoms are incorporated in their interstitial sites. For TiAlN, electrons of nitrogen atoms undertake double clamping of energy knot by coordinating both Ti and Al atoms. This is the cause that hard coating presents the increased elastic behavior and the decreased plastic behavior, which is also known since antiquity.

Suitable gas- and solid-natured atoms under their certain transition state behaviors are being controlled by the process parameters, they bind (adhere) by introducing the mechanism of double clamping of their certain filled state electrons (in gas-natured atoms) through certain energy knots of unfilled states (in solid-natured atoms). Appropriate vacuum conditions and high power enhance the hardness level of deposited coatings. Hard coatings introduce certain properties and applications due to the developing of non-regular structure where they involve the non-conserved energy, thus, engaging the non-conservative forces to work for their structure. The lifetime of hard coating depends on developing strategies according to their application. Not only hard coatings enable one to explore different phenomena of materials and their counterparts, but they also open many new areas of research.

4. Conclusions

In mechanism of developing hard coating, a gas-natured atom, when in suitable transition state, partially handovers the certain electron of outer ring to certain unfilled state (energy knot) of outer ring belonging to a solid-natured atom, when in suitable transition state also. Gas-natured atom binds to solid-natured atom from the rearward-side while in the attempt to evacuate. Here, solid-natured atom is in attempt to attain grounded level. Due to increase in its grounded behavior, bound gas-natured atom is also grounded with it in the form of deposition to substrate surface located in the suitable location of the deposition chamber. Depositing bound solid-natured atoms and

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 December 2018 doi:10.20944/preprints201802.0040.v7

gas-natured atoms are not in their original behavior of states. They are in certain transition behavior of states required for the binding, so, they switch their force-energy behaviors under set conditions.

The underlying science of developing hard coatings is in the manner that atoms of solid behavior perform negative work when undertaking the certain transition state as they attain ground points at the levels above to their original levels and atoms of gas perform positive work when undertaking the certain transition state as they attain ground points at the levels below to their original levels. For developing hard coating, gas-natured atoms react when just recovering from the transition state of increased orientating gravitational force with the solid-natured atoms, which are just recovering from the transition state of decreased orientating gravitational force. Two differently natured atoms bind to each other when they are in their transition states where certain electron of gas-natured atom experiences the exerting force to its north-sided tip through certain unfilled energy knot of solid-natured atom under their appropriate coinciding.

Under nearly a common ground point, suitable electron of gaseous transition state atom experiences north-sided tip through unfilled energy knot of solid transition state atom. Here, gaseous transition state atom (and that electron) decreases its potential energy under increasing the levitational force to gain the recovery state. On the other side, solid transition state atom (and that unfilled energy knot) increases the potential energy under increasing the gravitational force to gain the recovery state. This results into tightening (compressing) of clamp of unfilled energy knot to clamped-electron of losing potential energy under the mutual adjustment of contraction and expansion of solid transition state atom and gaseous transition state atom, respectively, which is permanent to adhere the binding of two differently natured atoms under their oppositely switched force-energy behaviors.

This fundamental study describing the development mechanism of hard coatings suggests the ways and means to develop smart deposition chamber systems where controlling pressure and temperature along with other parameters in the appreciable ranges maintain high precisions. This is very much possible through the automation in

addition to semi-automated deposition systems. This study suggests briefly which component is required to obtain planned results of materials' properties and characteristics. Controlling the lateral-orientation and adjacent-orientation of electrons for depositing their atoms at interface-stage and final layer-stage, respectively, will result into deliver the unprecedented performances of coated-tool, even for the case of dry machining. This really comes up with not only getting the unique benefits of coatings but their sustainable and controllable utilization.

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 and International colleagues at AMREC, SIRIM Berhad and at UTM Johor for their kind hospitality. First author thanks Professor Dr. Ali Ourdjini to review the work at several occasions and constructive feedback while studying at UTM who is now with the University of Ottawa.

References:

[1] M. Ali, Atoms of electron transition deform or elongate but do not ionize while inert gas atoms split under photonic current instead of electric. 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 under confined inter-state electron-dynamics. http://arxiv.org/abs/1611.01255

[4] M. Ali. Why Atoms of Some Elements are in Gas State and Some in Solid State, but Carbon Works on Either Side. https://www.researchgate.net/profile/Mubarak_Ali5

[5] M. Ali, Atomic Structure and Binding of Carbon Atoms, (2018). https://www.preprints.org/manuscript/201801.0036/v7

[6] M. Ali, Nanoparticles-Photons: Effective or Defective Nanomedicine, J. Nanomed. Res. 5 (6) (2018) 241-243.

[7] 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

[8] M. Ali, The study of tiny-shaped particles developing mono-layer dealing localized gravity at solution surface. http://arxiv.org/abs/1609.08047

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

[10] 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

[11] 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

[12] M. Ali, I –N. Lin, C. –J. Yeh, Tapping Opportunity of Tiny-Shaped Particles and Role of Precursor in Developing Shaped Particles. *NANO* 13 (7) (2018) 1850073 (16 pages).

[13] M. Ali, I –N. Lin, C. –J. Yeh, Predictor Packing in Developing Unprecedented Shaped Colloidal Particles. *NANO* 13 (9) (2018) 1850109 (15 pages).

[14] M. Ali, I –N. Lin, Phase transitions and critical phenomena of tiny grains carbon films synthesized in microwave-based vapor deposition system. *Surf. Interface Anal.* 2018;1–11. https://doi.org/10.1002/sia.6593

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

[16] M. Ali, M. Ürgen, Deposition Chamber Pressure on the Morphology-Structure of Carbon Films. https://arxiv.org/abs/1802.00730

[17] 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.

 doi:10.20944/preprints201802.0040.v7

[18] 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.

[19] 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.

[20] 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.

[21] 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.

[22] 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.

[23] 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.

[24] 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.

[25] 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.

[26] 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.

[27] 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.

[28] 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.

[29] 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.

[30] 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.

[31] 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.

[32] 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.

[33] 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.

[34] 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.

[35] 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.

[36] 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.

[37] 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.

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

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

[40] 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.

[41] 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.

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

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

[44] 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.

[45] 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.

[46] 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.

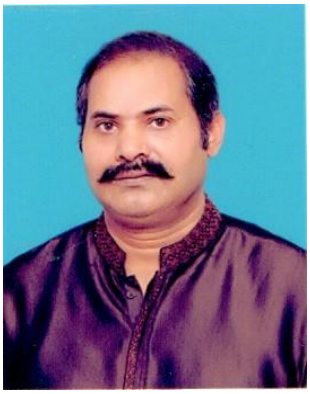
[47] C. Mitterer, F. Holler, F. Üstel, D. Heim. Application of hard coatings in aluminium die casting -soldering, erosion and thermal fatigue behaviour, Surf. Coat. Technol., 125 (2000) 233-239.

[48] 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.

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

[50] 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.

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 University Islamabad (previously known as COMSATS Institute of Information Technology), Islamabad, 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, Tohoku University, Japan to deliver scientific talk. 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 the PhD study by the Government of Pakistan, but he couldn't avail. He is author of several articles available at https://scholar.google.com.pk/citations?hl=en&user=UYjvhDwAAAAJ, https://www.researchgate.net/profile/Mubarak_Ali5.

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.