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Hard Coating Deposits: Incompatible Working Energy and Forced Behavior of Gas and Solid Atoms

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Abstract: Coating of suitable materials having thickness of a few atoms to several microns on a substrate is of great interest to the scientific community. Hard coatings develop under the significant composition of suitable atoms, where their energy and forced behavior while in certain transition state favour binding. In the binding mechanism of gas and solid atoms, electron belonging to outer ring filled state of gas atom undertakes another clamp of energy knot belonging to outer ring unfilled state of solid atom. Set process conditions develop the coating of gas and solid atoms when they process for a suitable composition. Atoms of suitable elements jointly develop their structure in the form of hard coating by locating common ground point, which is between their original ground points. Here, gas atoms increase the potential energy of electrons by decreasing levitational force of a controlled manner, whereas solid atoms decrease the potential energy of electrons by decreasing gravitational force of a controlled manner. So, hard coating is deposited because of incompatible working energy and forced behavior of atoms belonging to suitable elements. In TiN coating, Ti–Ti atoms bind due to the difference of expansion of their lattices, called energy knot nets, where one atom just lands on the already landed atom. An adhered N atom to Ti atom occupies the interstitial position vacant by the titanium atoms. As per set conditions of the process, atoms of different behavior deposit at substrate surface to develop structure of coating. The rate of ejecting or dissociating solid atoms depends on the type of source, parameters and the processing technique. In random arc-based vapor deposition system, depositing coating at substrate depends on several parameters. In addition to intrinsic behavior of atoms, different properties and characteristics of coatings emerged as per engaged forces by involved energy. In the coatings of different atoms, both energy and force are there in non-conservative modes. The present study sets new trends in the field of coating and other related fields.

Keywords: Fundamental science; Atomic behavior; Hard coating; Expansion and contraction; Energy and Force; 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 composition and deposition techniques are hotly debated. In this context, several materials comprising different composition of atoms are available underlining their deposition history. They highlight features of deposited coatings through their surface and interface study. To develop coatings of different characteristics, a variety of deposition techniques are available. In coatings, a minute quantity of deposited materials over less-important or not practically viable material gives the value-added benefits.

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. A variety of techniques are involved in depositing different sorts of coatings. Coatings are mainly used for two reasons; first, the potential use of coated part, and second for their substitution. Coating surface of suitable substrate results in different behavior of functioning, which is often in an astonishing way.

Atoms do not ionize while atoms of inert behavior split under the excessive population of photons having characteristic of current, as explored by Ali [1]. A neutral state silicon atom converts heat energy into photon energy, as identified by Ali [2]. Solid atoms belonging to certain elements evolve structures of different dimension and format as per the nature of their built-in electronic gauges, where conservative forces are involved to execute confined inter-state electron dynamics [3]. The origin for atoms of some elements in gas and some elements in solid state has been discussed [4]. A gas carbon atom originates several different states due to the involvement of typical energy and thereby, provides the path for filled state electron to migrate to nearby unfilled state [5]. Solid atoms under certain energy and forced behavior can develop tiny-sized particles for application in nanomedicine [6].

The prosperous assembling of colloidal matter into meaningful structure treats atoms and molecules of future materials as discussed by Glotzer and Solomon [7]. The understanding of the individual dynamics of the formation of tiny particles is essential before assembling them into the useful large sized particles [8]. The origin of physics and chemistry of materials through the formation process of tiny particles and their extended shape particles in pulse-based electron-photon and solution interface process was described by Ali and Lin [9]. Ali et al. [10] discussed the processing of gold and silver solutions at nearly identical conditions in the same method, where tiny and large particles of geometric structures developed only in case of gold. When the atoms were in certain transition state under the controlled conditions of energy and force, highly anisotropic particles of gold developed [11].

Different behavior of 'tiny grain carbon films' under Raman spectroscopy and energy loss spectroscopy were studied by Ali and Lin [12]. Switching morphological structure of grains and crystallites under slightly altered locally operating parameters in developing carbon films was discussed by Ali and Ürgen [13]. Under varying chamber pressure, a discernible change in the morphology and the growth rate of carbon films was observed by Ali and Ürgen [14]. These studies indicated a very different behavior of a carbon atom despite of having the same number of electrons. Clearly, such studies along with those referred to earlier provide the basic understanding of atoms belonging to different elements. Atoms of already discussed elements in those studies extract the information

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both in terms of their nature and behavior. The present study concentrates on the deposition of hard coating, where atoms related to both gas and solid are considered.

Some earlier studies have reported the history of arc-based technology along with initial efforts of deposition of suitable materials [15-18]. The basic engineering of d.c. arc discharge for different cathodes was investigated by Wroe [15]. The application of vacuum arc to deposit thin films and coatings along with electrodes was documented in a book by Boxman et al. [16]. The advantages and disadvantages of different cathodic arc sources were studied by Karpov [17] and the deposition of films through cathodic arc was studied by Brown [18], where the presence of the macroparticles is considered to be disadvantageous for some applications.

While depositing TiN coatings on different substrates under varying process conditions and employing 'cathodic arc physical vapor deposition', a different morphological structure along with hardness, surface roughness, friction coefficient, adhesive strength and overall performance of coated tools have been reported through different characterization and analysis tools [19-25]. The deposition of TiN coatings with different nitrogen gas flow rates by using cathodic arc vapor deposition technique has been studied by Ali et al. [19]. Effect of different nitrogen gas flow rates on the friction coefficient and surface roughness of TiN coatings has been discussed by Hamzah et al. [20]. Cathodic arc vapor deposition to optimize the thickness of TiN coating deposited on different substrates was employed by Ali et al. [21]. Evaluation of friction coefficient and surface roughness of different deposited TiN coatings under different temperatures was studied by Ali et al. [22]. Generation of macrodroplets at different parameters while depositing TiN was investigated by the same group [23]. Surface roughness of TiN coatings deposited on steel substrate under several parameters was investigated by Ali et al. [24] and the way the interlayer improved adhesiveness of TiN coating to steel substrate along with the growth mechanism of macrodroplets was studied by Ali et al. [25].

In addition, there are several other available studies in the literature targeting TiN coatings along with their processing techniques and analyses [26-33]. A droplet-free TiN coating under an improved and modified vapor deposition technique was deposited by

Elmkhah et al. [26]. The properties of TiN coating for targeted application were improved through the bombardment of active species by Oliveiraa et al. [27]. TiN coated as an interlayer material along with TaN was prepared and their science and application were elaborated by Vogel et al. [28]. Droplet-related defects produced through cathodic arc vapor deposition have important implications both for science and technology [29]. TiN coating on stainless steel substrates to study their tribological features under different conditions was deposited by Bahri et al. [30]. A review on the improvement of adhesive properties of TiN coatings was presented by Othman et al. [31]. TiN under its certain morphology and as an electrode material for dye-sensitized solar cell was studied by Jiang et al. [32]. Macroparticle content in cathodic arc deposited TiN coatings by varying the position of target, as reported by Harris et al. [33].

Furthermore, different types of hard coatings developed under various conditions have also been published extensively [34-45]. The hardness of Ti (C, N) was significantly improved under the control of microstructure and orientation [34]. The beginning of hard coatings to achieve firmness in two materials and protection of the coating adherence to tool against abrasion is studied by Bobzin [35]. Tribological properties under wet conditions were studied for different hard coatings including TiN [36]. A theoretical study for hard coating was presented by Music et al. [37], where both DLC and TiAlN based coatings were studied in the light of a new direction. A review on the features of TiN-based coatings related to wear resistance was studied by Santecchiaa et al. [38], where authors recommended to investigate hard and tough features of some important ceramic coatings along with the underpinning mechanism for the better future of spray technique [39]. The composition of deposited coatings and their achieved morphologies remained central to advance hard coatings for various cutting tool applications as discussed by Inspektor and Salvador [40]. A review on multicomponent, nanocomposite, and protective coatings was presented by Pogrebnjaka et al. [41], where performance of their characteristics was demonstrated. A review of the corrosion behavior of hard coatings on different steel substrates was investigated by Fenker et al. [42], where coating microstructure was expected to play only the secondary role for their corrosion behavior. Zirconium nitride coatings deposited on different substrates through cathodic arc deposition technique and high-power impulse magnetron sputtering for comparison purposes were discussed by Purandarea et al. [43]. Different hard coatings deposited on hot-working tool steel in the practical die casting service were evaluated by Mitterer et al. [44], and a comparison of TiAlN coatings was presented by Münz et al. [45], where different vapor deposition techniques were considered.

In addition to depositing hard coatings on suitable substrates for cutting tools' application, they are also in use for other applications. The suspension of hard coating to improve the scratch resistance of PMMA surface was studied by Tanglumlert et al. [46]. Effects of different parameters in depositing nanocomposite hard coatings for solar thermal applications were discussed by Soni et al. [47]. Hard features in the nano-hybrid coatings while depositing over the polymeric substrate were explored by Eshaghi [48]. Fracture toughness of $Ti_{1-x}Zr_xN$ hard coatings in relation to the elemental composition by using the internal energy induced cracking method was studied by Huang et al. [49]. According to Siow et al. [50], the properties of TiCN coating are controlled under the maintenance of C and N ratio while depositing on the tungsten carbide in cathodic arc physical vapor deposition technique. The significant properties of TiN coatings on Ti substrate for implant applications were investigated by Uddin et al. [51].

The basic idea discussed in above these studies is related to the properties and characteristics of deposited coatings, which are mainly subject to the change of process parameters, types of material used and processing approach. Here, it is discussed that hard coating is deposited because of incompatible working energy and forced behavior of their atoms.

In addition to the scientific details available for hard coatings discussed above, coatings are a 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 different hard coatings in general and investigating mechanism of developing TiN coating in particular.

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'. After the required cleaning, the samples having diameter such as 10 mm and thickness such as 6 mm were loaded in the coating system (Hauzer Techno Coating (HTC) 625/2 ARC). The complete deposition procedure along with the metallographic process of samples has been described in the earlier work of the same group [25]. Surface and interface cross-sectional views were captured by using field emission scanning microscope (FE-SM also known as FE-SEM, Model LEO-1525). The thickness of the deposited coatings was measured under the application of FE-SM and through the captured fractured cross-sectional image of the deposited coating on HSS substrate. Prior to coating TiN on treated HSS disc, an inter-layer of Ti atoms was deposited (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 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 and rotational speed of the substrate holder was controlled to deposit coatings of certain features [25]. 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) of a few hundred of nanometers to a few microns in size. The distribution of MDs is uniform throughout the surface of deposited coating. A large sized MD in the central vicinity of deposited coating is displayed in Figure 1 (a), which also shows mapping of the region, where the concentration of both Ti and N atoms is in different colors. Figure 1 (b) reveals 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 favorable conditions; different textures of a few nanometers thick deposited layer between the substrate and deposited TiN coating are visible in Figure 1 (b).

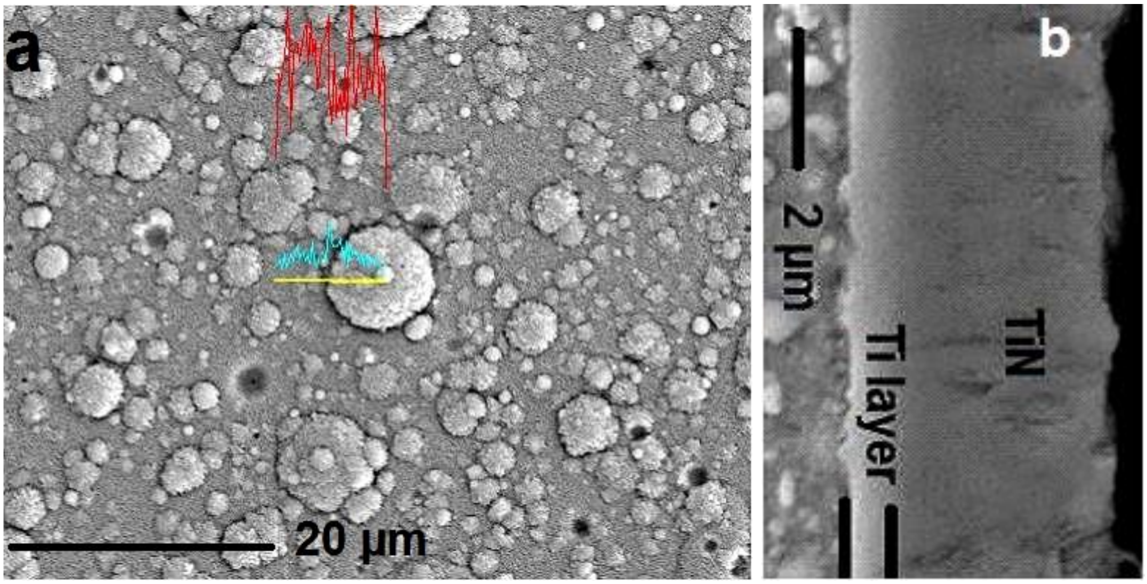

Figure 1: *(a) topographic view of TiN coating on HSS disc and (b) a few hundred nanometers thick titanium inter-layer shows contrast with respect to afterward deposited TiN coating having thickness ~4 µm*

Substrate surface comprising of different elements like W, Mo, Cr, V, C and Fe that attach to Ti atoms at initial stage improve the adhesion of the afterward deposited coating [19, 20]. Ti atoms bind to the substrate surface under suitable conditions of the deposited inter-layer. The substrate surface that consists of atoms of different elements is required to deposit Ti atoms up to a few nanometers' thickness. This inter-layer is required to improve the adhesive strength of the afterward deposited coatings. Some preliminary details regarding adhesive strength of TiN coating deposited under certain conditions in random arc-based vapor deposition system are discussed by Ali et al. [25].

Figure 2 exhibits 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 is also uniform. This indicates that MD contained less concentration of N atoms.

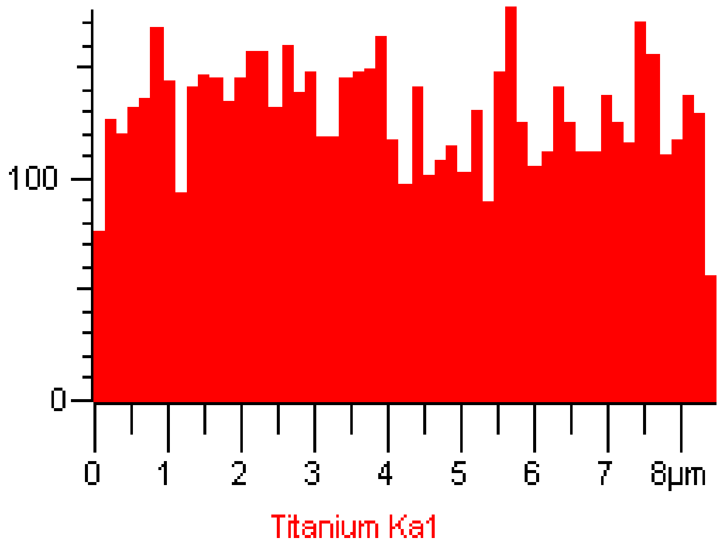

Figure 2: *Mapping of Ti atoms distribution along with the ratio of content*

Figure 3 shows the mapping of N content in TiN coating in the form of histogram, where N content is around 30% at the central point of MD displayed in Figure 1 (a). This indicates that the portion covered by N atoms in top front surface of coating contains 30% of its content and is uniform in distribution. However, the distribution of N atoms in the coating does not appear in the dense manner. There are several studies, where reduction of MDs for depositing hard coatings was investigated under the different process conditions [19, 21-23].

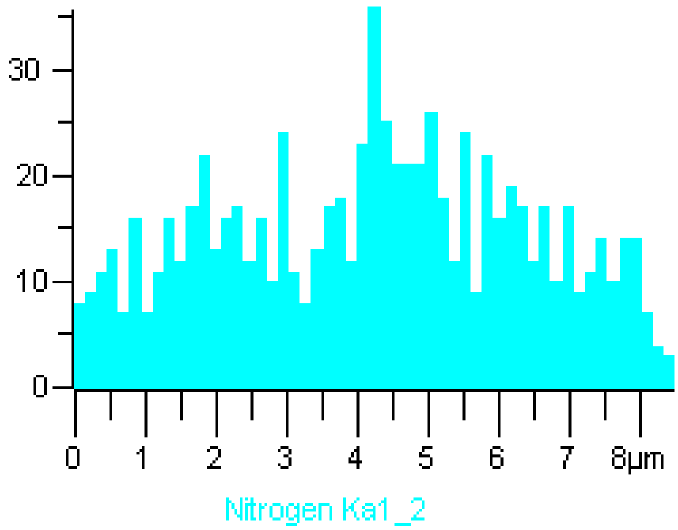

Figure 3: *Mapping of N atoms distribution along with the ratio of content*

A hard coating is related to category of refractory materials. So, this sort of coating does not conduct field despite the fact that its major component contains atoms of metallic behavior. Adherence of gas atoms to solid atoms result in the formation of coatings with low conductivity. Presence of the gas transitional atoms introduces insulating behavior of the hard coating. Because of this, a field of photonic current is interrupted to a large extent. Here, consistency of inter-state electron gaps in bound metallic transitional atoms becomes non-uniform under the hurdles of laterally orientated electrons of gas transitional atoms. The incorporated gas atoms build the bridges *via* their suitable electrons in bound atoms of conductive behavior element. So, photons of current deal with hurdle to leave the source even at the input end of applied field. A detailed study is presented by Ali [1] discussing the significance of inter-state electron gaps in atoms of different elements along with photonic current. Different materials constituting atoms of any type do not appear to study band gaps along with conduction and valence bands as the propagation of photons need the study of inter-state electron or photonic band gap [1]. The configurations of inter-state electron gaps in the atoms of certain elements along with their overall configuration in the lattice of a few atoms cluster at nanoscale, at micron, at millimetre or at bulk scale determine the characteristics of propagating or travelling photons. This indicates that the science of semiconductor materials or other types of materials requires new investigations to explain the origin of different phenomena. Here, a gas atom means an atom of gas behavior or gaseous state and a solid atom means an atom of solid behavior or solid state.

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 of different shape is utilized to eject atoms under the supply of high forcing/forced 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 metallic atoms source along with employed conditions of vapor deposition process, the properties of resulted coating are altered. The basic layout of ejecting Ti atoms and entering N atoms to deposit TiN coating is sketched in estimation as shown in Figure 4.

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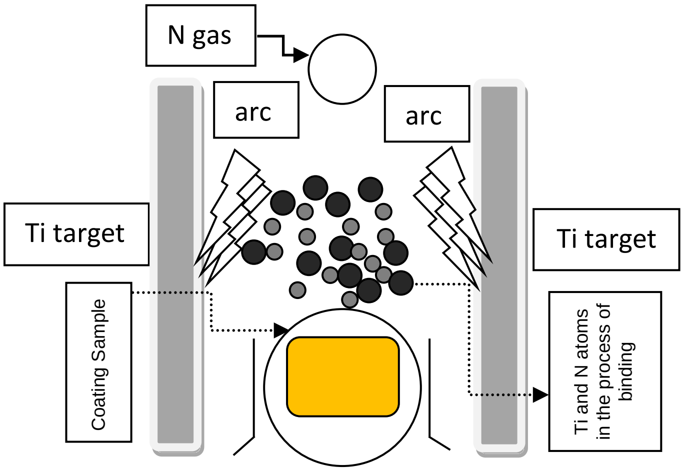

Figure 4: *The basic layout of depositing Ti atoms and N atoms to develop TiN coating at the surface of HSS substrate*

A newly observed atomic structure for atoms of Ti and N elements is shown in Figure 5 (a) and (b). The tiniest sized particles known as electrons are filled (arrested) in the hollow space formed by the inter-crossed overt photons. Each hollow space is covered by energy knot, which forms a filled or unfilled state of the electron. Depending on the number of filled and unfilled states, the energy knots forming the lattice of an atom are varied for each element [4]. Filled and unfilled states follow a particular symmetry to form atoms, where overt photons having characteristics of current are precisely inter-crossed. Atomic structure of atoms belonging to different elements along with origins of their different states has been explored by Ali [4]. A study by Ali [5] explored the lattice (energy knot net) and atomic structure of different state carbon atoms. In case where electrons do not fill the inter-crossed regions of energy knots (hollow spaces), they are related to unfilled states of their atoms. For Ti atom, total 32 states of electrons are available, but 24 states are filled by the electrons while 8 states are unfilled. In case of inner unfilled states of the atom, they are pressed by the covered filled states as indicated in (2) of Figure 5 (c). Both filled and unfilled states of Ti atom are constructed by the inter-crossed overt photons having dedicated length. The required numbers of overt photons are being inter-crossed with understanding of filled and unfilled states for an atom of each element. The unfilled states belonging to outer ring, where electrons do not occupy the position at the terminals of suitable chain of states in Ti atom, are shown in Figure 5 (c).

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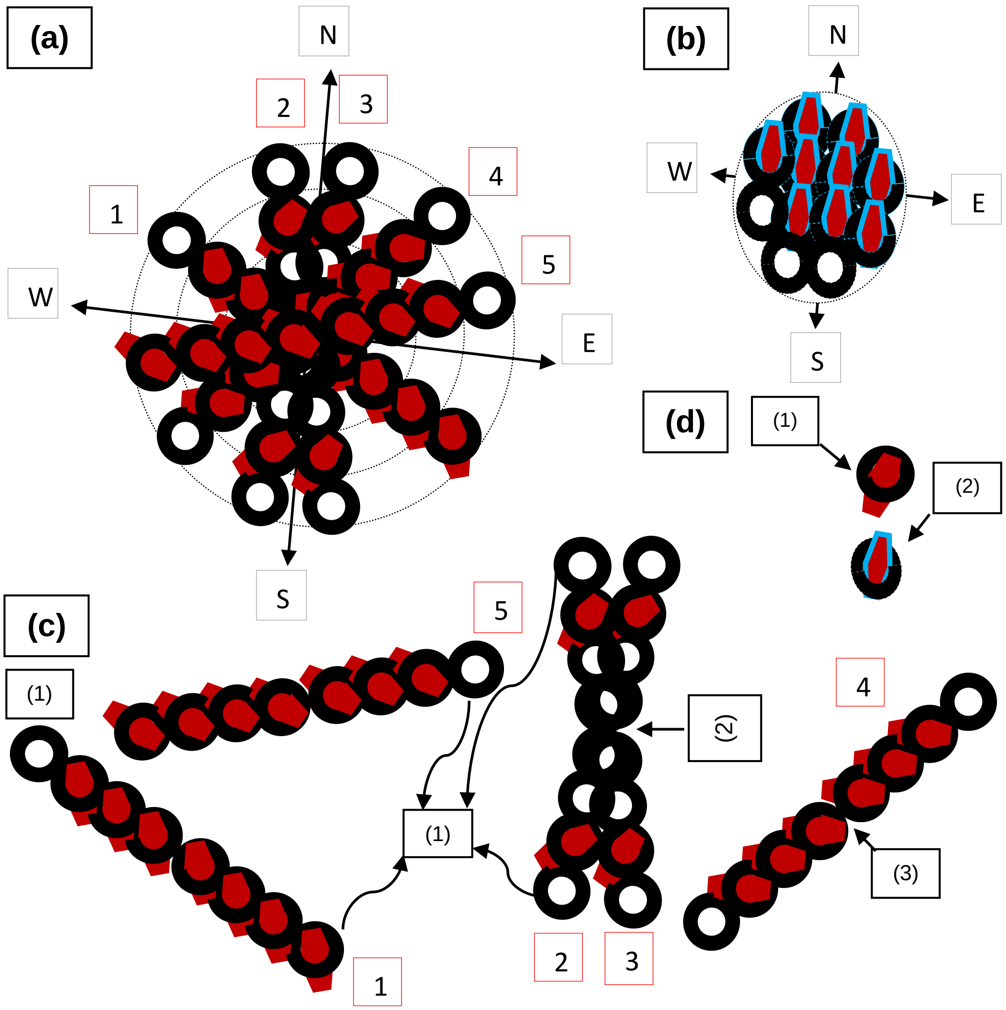

Figure 5: Atomic structure of **(a)** Ti atom (4 electrons in zeroth ring, 8 electrons in 1st ring, 10 electrons in 2nd ring and 2 electrons in 3rd (outer) ring along with 8 unfilled states), **(b)** N atom (4 electrons in zeroth ring, 5 electrons and 3 unfilled states in 1st ring/outer ring), **(c)** different chains of filled and unfilled states in Ti atom along with pressed states (zeroth, 1st, 2nd and 3rd rings); (1) unfilled and filled states at end of chains of states, (2) inner unfilled states are pressed by filled states and (3) oppositely-crossed overt photons, 8 'unit photons' shape of a wave in each case, constructed the chain of states (inner ones are filled states and outer ones are unfilled states) and **(d)** expanded energy knot clamping electron of Ti atom under increased energy (1) and contracted energy knot clamping electron of N atom under decreased energy (2)

Two overt photons comprising length of eight 'unit photons' cross while having their suitable symmetry, where they design or construct a chain of filled and unfilled states of electrons. As shown in Figure 5 (c), five such shapes are drawn and their precise inter-crossing at a common centre to form the 'energy knot net' of Ti atom with 24 filled states is highlighted. Expanded and contracted energy knots clamping electrons in Ti atom and N atom respectively are displayed in Figure 5 (d). Filled states of outer ring in the atoms of solid and gas donate the positive valency and negative valency respectively. In case of Ti atom, valency is +2, so, it has ‘8’ unfilled states. In case of nitrogen atom, valency is -3, so it has ‘5’ unfilled states. Hence, negative sign of valency in gas atoms indicates that their ground points are above the typical level of ground surface and positive sign of valency in solid atoms indicates that their ground points are below the typical level of ground surface.

In different coating technology units, regardless of the required numbers of atoms per unit area or volume as they 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 are different properties and characteristics of their coating. However, it appears that developing structure of TiN in the order of certain homogeneity is within the short-range order. Therefore, the deposited coating developed mainly under the mixed behavior of structure. 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 the outer ring. Being a solid atom, it should possess unfilled states above the east and west poles, both on left and right sides of the north-pole. As the titanium element belongs to grounded format, so electrons of filled states (of outer ring) in its atoms remain below the east and west poles, both on left and right sides of the south-pole. On the other hand, five filled states in the outer ring of N atom allow a smaller number of unfilled states in the outer ring. Due to the gas behavior of N atom, it contains several filled states of outer ring, where majority of the electrons (filled states) are expected to be above the east and west poles, both on left and right sides of the north-pole. 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. So, a suitable electron of gas atom is being clamped by unfilled energy knot of solid 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 prevails when atoms of gas and solid are in their suitable transition

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states. Atoms adjust potential energy of their electrons as per exertion of orientationally controlled force when in their suitable transition states [4]. Therefore, two different behavior atoms (Ti and N) develop affinity in terms of strong binding.

A metallic target developed under the solidification of transition state atoms, most probably when they were in their re-crystallization transition state. The processed ore of metallic target is on ground surface, where exerting forces are functioning in surface format but their atoms in original solid state are below the typical level of ground surface. Similarly, gas atoms compressed in the container are in the re-crystallization transition state as well on the ground surface; whereas, they are above the typical level of ground surface in original gas state. On ejection of solid atoms from the target and flowing of the compressed gas atoms from the container, they are again in transition to restore their original states. Therefore, to revive their original state behavior, they react (fast interact) just above the substrate of their deposition. At the instant of their reaction, they work nearly opposite in terms of energy and forced behaviors to the ones when in their original behavior. Here, under suitable interactions, electrons of gas atoms enter to unfilled states of solid 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 atoms are in the re-crystallization state, their electrons go downward under infinitesimal displacements, where they decrease their levitational force by increasing potential energy. Contrarily, electrons of the gas atoms are still more than 50% upward at mid of their clamped energy knots. When solid atoms are in the re-crystallization state, their electrons go upward under infinitesimal displacements, where they decrease their gravitational force by decreasing their potential energy. However, the electrons of the solid atoms are still more than 50% downward direction at mid of their clamped energy knots. A suitable electron of the gas atom undertakes another clamp of suitable energy knot belonging to solid atom. When gas and solid atoms attain their suitable transition states, where electron of a gas atom experiences exerting force to its north-sided tip through hollow space of unfilled energy knot of solid atom, they favor binding. Thus, that electron undertakes another clamp of energy knot in addition to its own. This mechanism of undertaking double clamping of suitable electron by suitable

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unfilled energy knot in different atoms is under their favorable transition states. When many such different atoms per unit area adhere to the same scheme, they develop 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 state. On the other hand, entered gas atoms to the chamber are in the expansion of energy knots clamping electrons because they are near to ground surface now instead of being above the typical level of ground surface. Therefore, different atoms work for opposite behavior of their energy and force. Just at an instant of recovering original behavior, they bind under suitable coordination, where electron of gas atom undertakes another clamp of unfilled energy knot of solid atom. Therefore, solid atoms have already done work negatively while arriving near to the typical level of ground surface from the south-side while gas N atoms have already worked positively while arriving near to the typical level of ground surface from the north-side. To recover the state behavior of two different atoms while to be in suitable transition states, they just work for opposite behavior of their energy and force, where work done by the gas atom is negative, while work done by the solid atom is positive. So, they react to undertake double clamping of the suitable electron (of the gas atom) through suitable unfilled state (of the solid atom).

Ti is known to have metallic character, where filled state electrons of atoms deal with their maximum gravitational force. So, they also possess the maximum expansion of their clamped energy knots. Thus, the electrons of Ti atoms keep the original ground point below the typical level of ground surface. N atom belongs to gas state that maintains ground point above the typical level of ground surface, where its electrons experience the maximum potential energy. This way, 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 belongs to N atom clamped by another energy knot, clamping to unfilled state of outer ring in Ti atom. Given conditions of the process enable another clamping of the energy knot (belonging to Ti atom) to a suitable filled state electron of the N atom. Here, energy is involved to

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engage the forced functioning in both space and grounded format. But this is under the maintenance of mid-point of gas and solid atoms in the surface format.

The electrons of N atoms undertake double clamps of energy knots while visualizing the exerting force (to tip-sided regions) from hollowness regions of unfilled states (energy knots) of Ti atoms. Here, gas state atoms attempt to leave the ground point in surface format (just at substrate surface) to occupy their original ground point in space format. The solid ones are in the attempt to leave the ground point of surface format (just at substrate surface) to be in the original grounded format. Suitable transition state atoms (belonging to gas state) undertake double clamps of targeted energy knots (belonging to solid atoms) for their targeted electrons under favorable coinciding. The mechanism of double clamping of energy knots of Ti atoms to electrons of N atoms is shown in Figure 6. Binding of Ti-Ti 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. Here, N atoms show their interstitial positions.

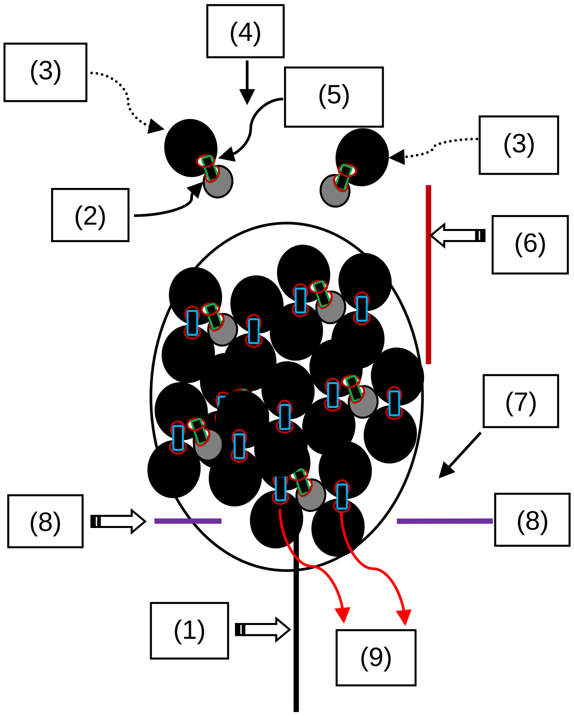

Figure 6: *Mechanism of double clamping of suitable energy knots (of solid atoms) to suitable electrons (of gas atoms already clamped by their energy knots) along with mechanism of binding atoms in Ti–Ti; (1)*

solid atoms retain original ground point below the typical level of ground surface, (2) suitable electron of N atom is just recovering the increased expansion of clamped energy knot under the recovery of increased potential energy, (3) an atom ejected from Ti target, (4) inlet of N gas, (5) energy knot clamping unfilled state of Ti atom is just recovering the decreased expansion under the recovery of potential energy of electrons of filled states, (6) gas atoms retain original ground point above the typical level of ground surface, (7) HSS disc, (8) solid and gas atoms attained ground point at a common point (mid-point) at surface of HSS substrate and (9) Ti–Ti binding

Under the action of tailored energy behavior of N atoms and Ti atoms, they react, which results in their adhesion to develop TiN coating on the surface of the substrate. Solid atoms in original state behavior keep gravitational force of their positioned electrons to the maximum extent. This is due to their ground points in grounded format. Here, electrons possess the maximum potential energy under the maximum expansion of clamped energy knots. This way, energy knots constructing unfilled states in those atoms also expand maximally. Electrons deal with fully gravitated behavior of exerting force along the relevant poles. Nevertheless, gas atoms in original state behavior keep their ground points in space format. This way, their electrons possess the minimum potential energy. The clamped energy knots to electrons are in their maximum contraction. Hence, energy knots related to unfilled states in gas atoms also remain in their maximum level of contraction. Electrons deal with orientating levitational force along the relevant poles to the minimum extent.

When a Ti atom lands at substrate, it attempts to recover its original solid state, where its electrons start to gravitize. However, prior to being fully gravitized, an adequate expansion of its ‘energy knot net’ takes place, which is under the adjustable potential energy of electrons. On the contrary, after landing, Ti atom attains ground point on the surface of previously landed atom due to the less expansion of net of energy knots. This way, a certain electron of less-expanded landed Ti atom (where it is pointing toward the downward side) is being visualized by hollowness of a certain unfilled energy knot of a more-expanded landed Ti atom (where it is pointing toward the upward side) to bind under the minute difference of their ground points. This results in the binding of two identical atoms. Forcefully ground N atoms when attempt to recover state to go into original gas state, their certain electrons are visualized (as experiencing force) by hollowness of certain unfilled energy knots of Ti atoms. This visualization of

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exerting force to tip-sided region of electron (of gas atom) by the hollowness of unfilled energy knot (of solid atom) is from the rear side (back side of solid atom). These binding mechanism of two different atoms (Ti-N) and the same atoms (Ti-Ti) provide the site for N atom to place (trap) at the interstitial position of the Ti atoms. Binding of N atoms at interstitial positions of bound Ti atoms is also shown in Figure 6. When atoms of N (or other suitable elements) and Ti (or other suitable elements) are in their original states, they engage energy under the exerting forces of fixed poles of their electrons. However, the situation becomes different when they undertake certain transition (liquid) state, where in the solid atoms, the involved energy is directly proportional to the engaged force, i.e., gravitational force exerted to electrons along their relevant poles. In the gas atoms, involved energy is inversely proportional to the engaged force, i.e., levitational force exerted to electrons along their relevant poles. Further details of energy and force or force and energy relationship in gas atoms and solid atoms were given in a separate study [4].

When solid 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 gas atom, which is also recovering from the certain transition state. The reaction of gas atom when in ground point, which is just above the substrate surface, is at the level of exerting force in surface format instead of the level of exerting force in space format. The reaction of metallic nature atom when in ground point, which is also just above the substrate surface, is also at the level of exerting force in surface format instead of the level of exerting force in grounded format. This results in the binding of different atoms at a common ground point. The common ground point is at the mid of ground points of gas atom exerting force to electrons originally in space format and solid atom exerting force to electrons originally in grounded format in their original state behavior. The binding of gas and solid atoms under suitably attained transition states engages the forces of both upward (space) and downward (grounded) formats as per involved energies. Hence, their structure gets hard.

The similar sort of mechanism is anticipated in binding of bi-metallic composition (atoms) when bound to bind to gas atoms, for example, TiAlN. Again, low measured

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hardness coating of CrN (compared to TiN) involves the mechanism of binding their different atoms under similar lines, where high probability of binding is involved as Cr atom contains many unfilled states for the outer ring (compared to Ti atom), leading to low surface roughness of CrN coating when compared to TiN coating [25]. In addition, the greater level of homogeneity of binding atoms while developing structure also influences the surface roughness. A similar approach may be considered to explore the science of other hard, moderate hard and even less hard (soft and porous) materials. A slightly different originating scientific mechanism may be anticipated in case of TiCN coating because of the involvement of carbon atom, which requires additional lines to express the science of binding different atoms. Reaction of gas and solid atoms confirms the engagement of force as per supplied energy, where their electrons adjust the expansion and contraction of clamped energy knots respectively. In this case, the energy is being involved and the force is being engaged.

The electron of outer ring belonging to gas 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 atom (Cr-atom). At the time of recovering transition state of Cr atoms, they are just at the substrate surface. Thus, they react with N atoms, which are also just on substrate surface and at the instant of recovering transition state. Cr atoms on landing undertake less expansion of their ‘energy knot nets’ than the ‘energy knot nets’ of already landed Cr atoms. They devise the unit (primitive) cell of hard coating if they are under the appropriate coinciding. Here, N atoms are also incorporated at interstitial sites. For TiAlN, electrons of N 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 and the decreased plastic behavior, which is also known since antiquity.

Developing hard coating is related to involvement of non-conserved energies, where non-conservative (frictional) forces are engaged. However, whenever the force element is involved first, the energy is engaged in case of atoms of silicon solar cell [2]. Conservative forces are involved to configure the energy in the form of forcing energy (photon), where a photon having characteristic of current is discussed [1]. In another

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study, different types of photons are explored [2]. Overt photons of different lengths having different numbers are used to construct unfilled and filled states of electrons describing the origins of atoms belonging to different elements of periodic table [4]. A lattice or net of carbon atom is formed by the inter-crossed overt photons (of certain length and number) precisely [5].

Apparently, the formation of hard coating does not signify the presence of gravitational and levitational forces. However, electrons of different atoms while retaining their occupied states require adjusting and maintaining, and further necessitating infinitesimal displacement for binding. This is achieved by the involved energy through the engagement of a carried force. In the deposition chamber, randomly distributed arc spotting at the target to eject metallic atoms contained both energy and force. Entitled involving energy to maintain required transition states of different atoms at an instant of their binding also engages the force that has the components of both gravitation and levitation to maintain that level.

Process energy regulates the structure of hard coating comprising different atoms under the engagement of forces, which is in the transitional manner. The process energy maintains the required (transition) states of solid and gas atoms through the potential energy of electrons controlled at the instant of their binding. At the instant of binding two different atoms, a gas (N) atom is not in its original (full) levitational behavior of force, but it is in a decreased levitational behavior of force, where the potential energy of its electrons is increased. So, a gas atom has energy and force in inversely proportional relationship while dealing with transition state. On the other hand, a liquid transitional gas atom works for its energy and force behavior opposite to the energy and force behavior when it is in the original gas state. At the instant of binding two different atoms, a solid atom is not in its original (full) gravitational behavior of force, but it is in a decreased gravitational behavior of force, where the potential energy of its electrons is also decreased. So, a solid atom has energy and force in directly proportional relationship while dealing with transition state. Under required (transition) state for solid atom, the potential energy of electrons was decreased to lower their exerting gravitational force. The behavior of energy and force of solid atom is different from the

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behavior of energy and force of gas atom [4]. On the other hand, a liquid transitional solid atom works for its energy and force behavior opposite to the energy and force behavior when it was in the original solid state.

Certain gas and solid atoms, under suitable behaviors of transition states adhered to the process parameters. Different atoms bind by introducing the mechanism of double clamping of energy knot (belonging to certain unfilled state of outer ring in solid atom) to electron (belonging to certain filled state of outer ring in gas atom). Appropriate vacuum conditions and high power enhance the level of hardness of deposited coatings. Hard coatings develop certain properties and characteristics because of their non-regular structures, where they possess non-conserved energies under the engagement of non-conservative forces. The lifetime of a hard coating depends on its developing strategies. In addition to show several remarkable applications, hard coatings also help to understand the behavior of different interacting counterparts. This way, they open many new areas of research.

4. Conclusion

In the mechanism of developing hard coating, a gas atom when in suitable transition state, partially hands over a suitable electron of its outer ring to a suitable unfilled state (energy knot) belonging to outer ring of a solid atom if it is also in certain transition state. Gas atom binds to solid atom from the rear side while attempting to restore original behavior. Here, solid atom attempts to attain its ground point in grounded format. Due to the already attained ground point (in surface format) of gas atom under certain transition state, it binds solid atom to land on the substrate surface in the form of deposition. In the deposition chamber, the substrate is placed below depositing (condensing) atoms for adhering them to the surface. Deposited solid atoms and gas atoms are not in their original state behavior. They are in certain transition states required for their binding.

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. They attain ground points at the levels above their originally attained level. Atoms of gas behavior perform positive work when undertaking the certain transition state. They attain ground points at the levels below their originally attained level. For developing hard coating, gas atoms react with the solid atoms, recovering from the transition state of decreased orientating levitational force of their electrons. Here, reacting solid atoms are just recovering from the transition state of decreased orientating gravitational force of their electrons. Two different atoms bind when they are in desirable transition states, where suitable electron of gas atom experiences the exerting force to north-sided tip through suitable unfilled energy knot of solid atom, on the appropriate coincidence. Under the adjustable amount of heat energy, electrons of an atom adjust potential energy. In deposited hard coating, maintenance in potential energy of each electron is through the engagement of orientated force.

Under a common ground point, suitable electron of transitional gas atom experiences force to north-sided tip on visualizing through suitable unfilled energy knot of transitional solid atom. Here, gas atom (and that electron) increases potential energy under decreased levitational force to attain required transition state. On the other hand, solid atom (and that unfilled energy knot) decreases its potential energy under decreased gravitational force to attain that required transition state. On just recovering those required transition states of gas and solid atoms, they bind, which is followed by the tightening of clamp (of unfilled energy knot) to electron (of already clamped by own energy knot). This occurs due to the mutual adjustment in contraction behavior (of solid atom) and expansion behavior (of gas atom). This is achieved by the mutual adjustment among energy knots of solid atom and mutual adjustment among energy knots of gas atom. Adjustment in contraction of energy knots in net of solid atom and adjustment in expansion of energy knots in net of gas atom result in the binding of atoms of two different behavior. So, hard coating is deposited because of their incompatible working energy and forced behavior.

To deposit TiN coating on a desirable substrate, energy and force of transitional gas and solid atoms work nearly opposite to energy and force when in the original states. Certain transition metals govern hard features of coating as a result of their affinity to gas atoms because one is originally related to exerting force (to electrons) in grounded format and the other is originally related to exerting force (to electrons) in space format.

However, under desirable switching of energy and force, atoms of different behavior attain their certain transition states enabling ground points nearly in the mid-regions of exerting forces in grounded format and space format. Hence, transitional atoms of different behavior bind when exerting forces are nearly adjusted for the exerting forces in the surface format. This is achieved through the supply of required amount of energy.

This fundamental study describing the development mechanism of hard coating suggests the ways and means to develop smart deposition chamber systems, where controlling pressure and temperature along with other parameters in the appreciable ranges can maintain high precisions. This is very much possible through the automation in addition to semi-automated deposition systems. This study suggests in brief the kind of component that is required to obtain planned results of material properties and characteristics. This will help to achieve the unique benefits of coatings and their meaningful utilization.

Controlling the lateral and adjacent orientation of electrons for depositing atoms at interface and final layer stage (surface) respectively will result in the unprecedented performance of tools. When the application of such coating is for an ultra-precision machining, it can deliver high-performance in case of dry machining. Such strategies will not only save the revenue but also keep the environment clean.

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