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

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Abstract –Coating of suitable materials having thickness of 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-natured atoms where their force-energy behaviors when in certain transition state favour binding. In the binding mechanism of suitable 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 binding of different-natured atoms when processing their suitable composition in a system. Atoms of different nature develop structure in the form of hard coating by locating their ground points between the original ones. Here, gas-natured atoms increase the potential energy under decreasing levitational force of electrons, whereas, solid-natured atoms decrease the potential energy under decreasing gravitational force of electrons. In TiN coating, Ti–Ti atoms bind under the difference of expansion of their lattices, called nets of energy knots, where one atom just lands on the already landed atom. An adhered N-atom to a Ti-atom forms its position among four Ti-atoms where N-atom occupies the interstitial site of Ti-atoms. Two oppositely working force-energy behavior atoms deposit in the form of coating at substrate surface as per set conditions of the process. The rate of ejecting (or dissociating) solid-natured atoms depend on the nature of their source (target), process parameters and processing technique. 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 their 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 nature; Hard coating; Expansion and contraction; Force-energy behavior; 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 in hot debate. In this context, several materials comprising different composition of atoms are available underlining their deposition history, features of deposited coatings along with their surface and interface study. A variety of deposition techniques are also available in the literature to develop coatings with different properties and characteristics. 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.

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 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 do not elongate and atoms belonging to inert gases split under the excess propagation of photons characteristic current, is explored by Ali [1]. A neutral state silicon atom transforms heat energy into photon energy, was revealed by Ali [2]. Solid-natured atoms belonging to certain elements evolve structures of different dimension and format as per the nature of built-in electronic gauges where conservative forces are involved to execute their confined inter-state electron-dynamics [3]. The origin for atoms of some elements in gas-state and some elements in solid-state has been 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 to nearby unfilled state [5]. Solid-atoms under certain force-energy behavior can develop tiny-sized particles for application in nanomedicine [6].

The prosperous assembling of colloidal matter into meaningful structure will treat atoms and molecules of future materials was discussed by Glotzer and Solomon [7]. The understanding of the individual dynamics of tiny particles formation is essential before assembling them into the useful large sized particles [8]. Origin of physics and chemistry of materials through the formation process of tiny particles and their extended-shape particles in pulse-based electron-photon 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 a same method, where tiny and large particles of geometric structures developed only for the case of gold. When the atoms were in their certain transition state under the controlled conditions of force-energy, highly-anisotropic particles of gold were developed [11].

Different behaviors of 'tiny grains carbon films' under Raman spectroscopy and energy loss spectroscopy were studied by Ali and Lin [12]. Switching morphology-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 growth rate of carbon films was observed by Ali and Ürgen [14]. These studies indicated a very different behavior of a carbon atom within the same element. Clearly, such studies along with those referred in the above-paragraphs provide the basic understanding of atoms belonging to different elements. Atoms of discussed elements in those studies extract the information both in terms of their nature and behavior. As the present study concentrates on the deposition of hard coating where atoms related to both gas-state and solid-state are considered. Hence, above-cited studies are important in grasping some idea and the developing mechanism of hard coating at basic level.

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 study was documented in the form of book by Boxman et al. [16], the advantages and disadvantages of different cathodic arc sources were studied by Karpov [17] and deposition of films through cathodic arc was studied by Brown [18] where 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 morphology-structure along with hardness, surface roughness, friction coefficient, adhesion strength and overall performance of coated tools have been reported [19-25]; through different characterization and analysis tools, 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 were 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 how the interlayer improved the adhesion 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]; 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 on scientifically and technologically sides [29]. TiN coatings 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 adhesion 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] and macroparticle content in cathodic arc deposited TiN coatings under varying the position of target was 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 was with how 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 was studied for different hard coatings including the 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 new direction, a review on the features of TiN-based coatings related to wear resistance were studied by Santecchiaa et al. [38] where authors recommended to investigate hard and tough features of some important ceramic coatings along with underpinning mechanisms for the better future of spray technique [39], the compositions of deposited coatings and their achieved morphologies are remained the paddles to advance hard coatings for various cutting tools applications as discussed by Inspektor and Salvador [40], a review on multicomponent nanocomposite protective coatings was presented by Pogrebnjaka et al. [41], where performance of their characteristics were 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 was 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]. Effect of different parameters in depositing nanocomposite hard coatings for solar thermal applications was 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 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 used and processing approach. Here, it is discussed that hard coating is deposited because of the oppositely working force-energy behaviors of their different-natured atoms.

In addition to the discussed scientific details available for hard coatings, 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 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'. After the required cleaning, the samples having diameter: 10 mm and thickness: 6 mm were loaded in the coating system (Hauzer Techno Coating (HTC) 625/2 ARC). The complete deposition procedure along with metallographic process of samples has been described in the earlier work of 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 few hundred of nanometers to 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 shown 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) 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 favorable conditions, different textures of few nanometers thick deposited layer between the substrate and deposited TiN coating is visible in Figure 1 (b).

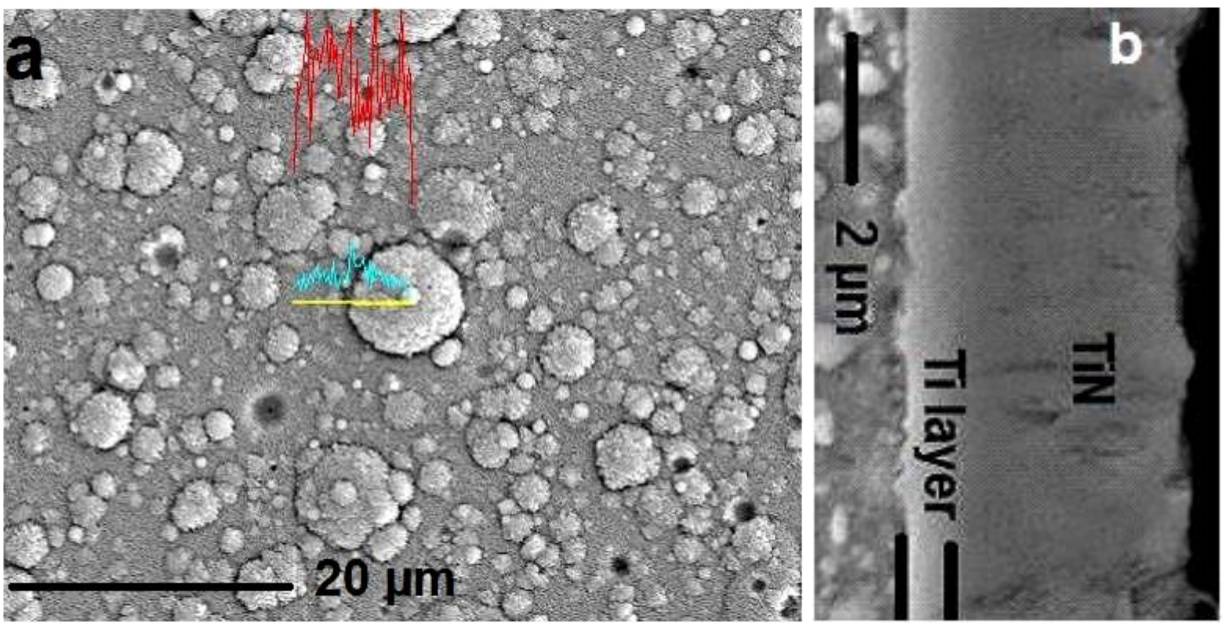

Figure 1: *(a) topographic view of TiN coating on HSS disc and (b) few hundred nanometers thick titanium inter-layer shows contrast with respect to afterward deposited TiN coating having thickness ~4 µm*

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 comprised of atoms of different elements is desired to deposit Ti-atoms of different force-energy behaviors upto few nanometers thickness. This inter-layer is required to improve the adhesion strength of the afterward deposited coatings. Some preliminary details regrading adhesion strength of TiN coating deposited under certain conditions in random arc-based vapor deposition system are discussed by Ali et al. [25].

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 is also uniform. This indicates that MD contained less concentration of N-atoms.

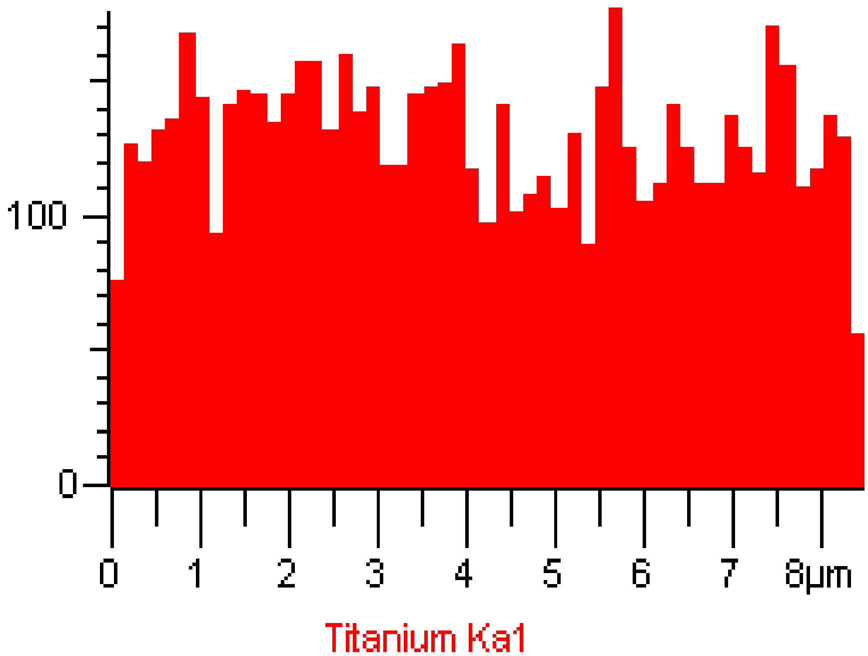

Figure 2: *Mapping of Ti-atoms distribution along with the ratio of content*

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 shown 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 is not appeared in the dense manner.

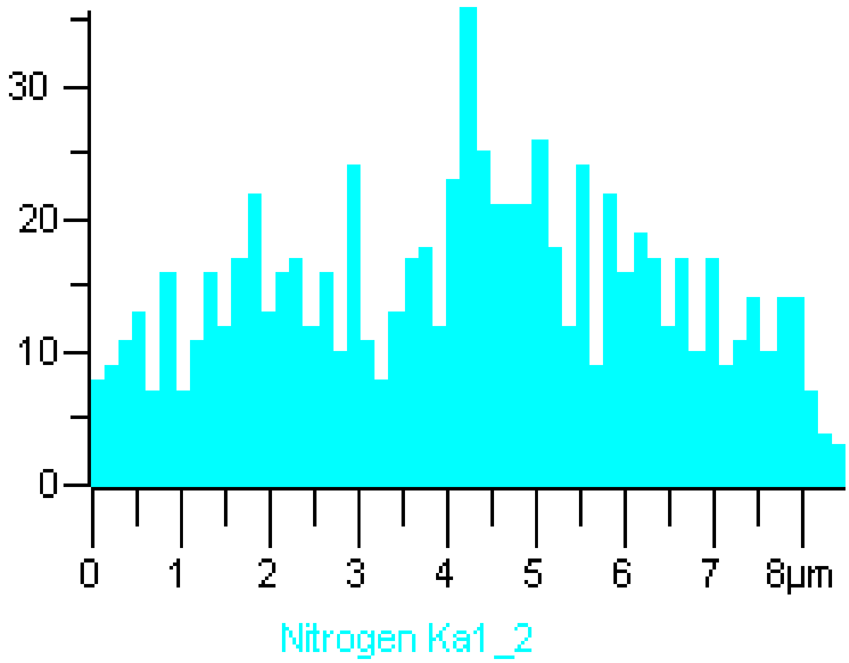

Figure 3: *Mapping of N-atoms distribution along with the ratio of content*

There are several studies where reduction of MDs for depositing hard coatings was investigated under the different process conditions [19, 21-23].

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 gas-natured atoms to solid-natured atoms result in the formation of coatings with low conductivity and gas-natured 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 deposited coating. In the case of disordered structure, it is only within the short-range order. The incorporated N-atoms build the bridges *via* their certain electrons where they undertake another clamp of unfilled energy knot belonging to outer rings of Ti-atoms resulting into lowering the propagation of photonic current also known as electric or electronic current. A detailed study is presented by Ali [1] discussing 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) through certain materials (mediums) no more requires the concepts of band gap along with conduction and valence bands. The configuration of inter-state electron gaps in the atom of certain element along with the overall configuration of inter-state electron gaps formed at the scale of few atoms cluster, at nanoscale, at micron scale, at millimetre scale or at bulk scale determine the characteristics of propagating/travelling fields (of photons having wavelengths in current or having wavelengths in other features of their frequency). This indicates that science of semiconductor materials or other types of materials requires 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 source 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).

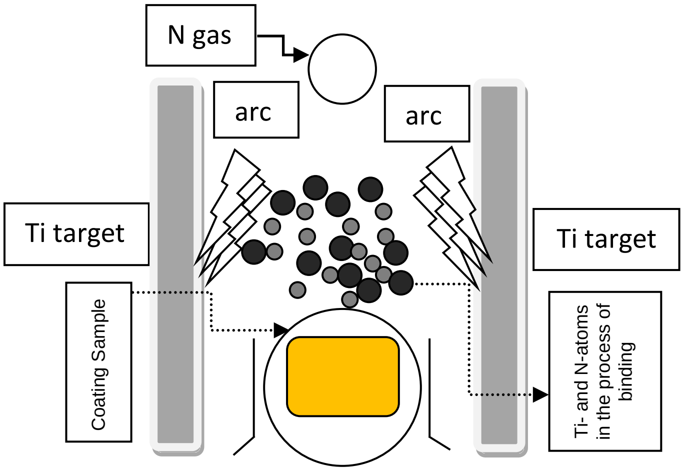

Figure 4: *The basic layout of depositing Ti-atoms and N-atoms to develop TiN coating at the surface of HSS substrate*

A newly observed atomic structure for atoms of Ti and N elements is shown in Figure 5. The tinniest sized particles known as 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). Atomic structure of atoms belonging to different elements along with origins of their different states has been explored by Ali [4]. A study discussed by Ali [5] explored the lattice (energy knot net) and atomic structure of different state carbon atoms. In the case where electrons don't fill the inter-crossed regions of energy knots (hollow spaces), 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 unfilled. In the case of inner unfilled states of the atom, they are 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. The 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. A detailed study has discussed different types of photons and nature of the overt photons [2], whereas, atomic structure in different elements is reported in another study [4].

Two overt photons comprising of 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 states are highlighted. 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 that their ground points are at above the average-leveled ground surface and positive sign of valency in solid-natured atoms indicates that their ground points are below the average-leveled ground surface.

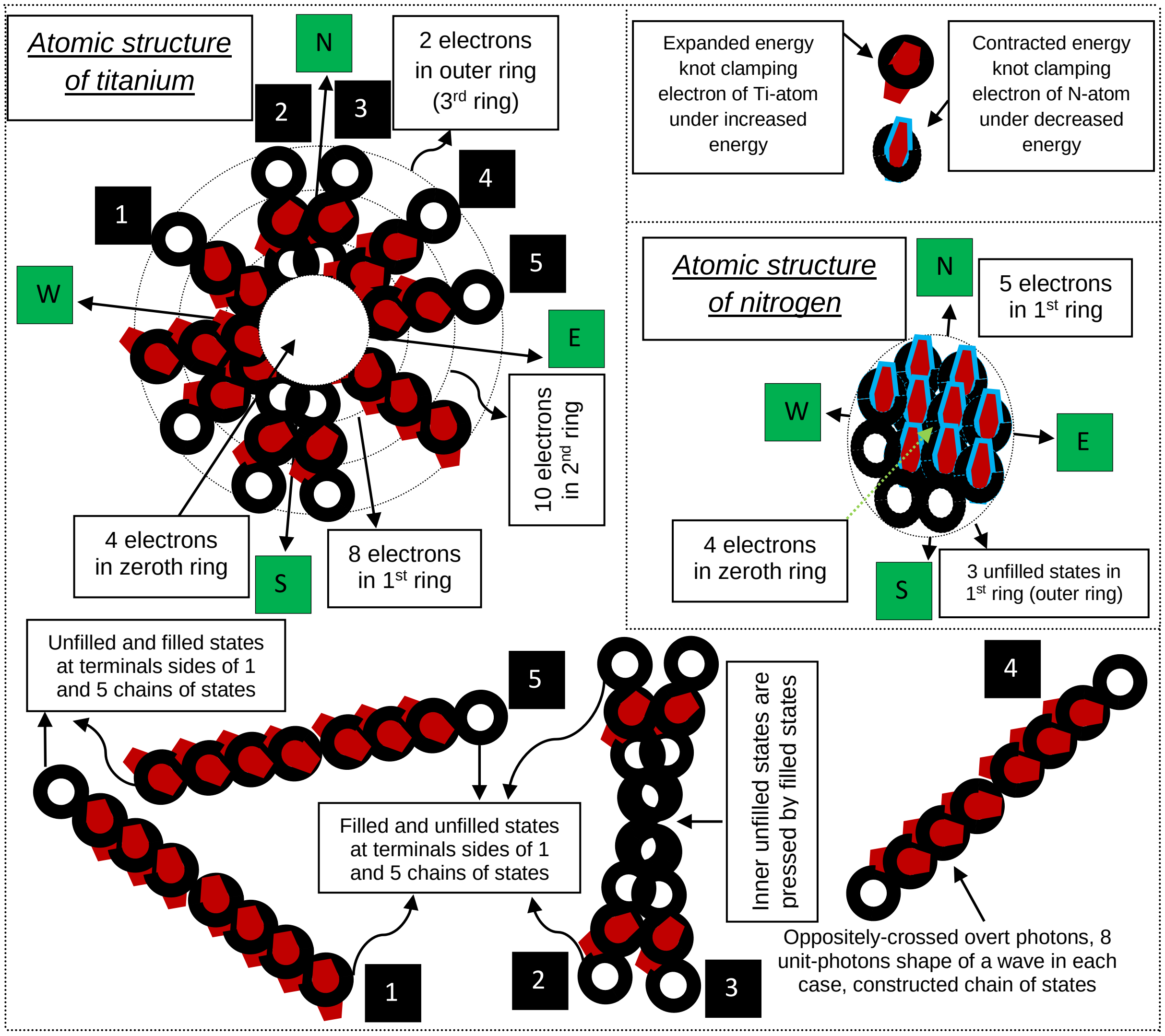

Figure 5: *newly observed atomic structure of atoms belonging to Ti and N elements; involved different chain of states are shown at bottom indicating filled, unfilled states and pressed (unused) states for Ti-atom*

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 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 is 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 enable 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. 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 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 (surface-format) but their atoms in original solid-state are to be below the ground surface (in grounded-format). 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 above the ground surface in original gas-state. 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 and would like to restore their original states. So, in an attempt to revive 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 oppositely(nearly) worked in their force-energy behavior. 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 their 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 applied) force to its north-sided tip from unfilled energy knot of solid-natured 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 certain electron by certain unfilled energy knot in different-natured atoms is under their certain transition states. When many such different-natured atoms per unit area adhere under 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-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 work for opposite behavior of their force-energy. 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 worked positively (arriving near to ground surface from the north-side). To recover the state behaviors of two different-natured atoms to be in suitable transition states, they work for opposite behavior of their force-energy, 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 their original solid-state. A N-atom belongs to gas-state and 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 clamped 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 of space-format and grounded-format by maintaining their mid-point in the surface-format. This results into attaining their ground point neither at above ground surface nor at below ground surface. So, different-natured atoms 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-natured 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 the exerting force through unfilled states (energy knots) of Ti-atoms, where gas-state atoms attempt to leave the ground point of surface-format (just at substrate surface) to be in the original space-format while 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-natured atoms) for their targeted electrons under 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 shown in Figure 6, where N-atoms are mainly positioned at interstitial sites of Ti-atoms.

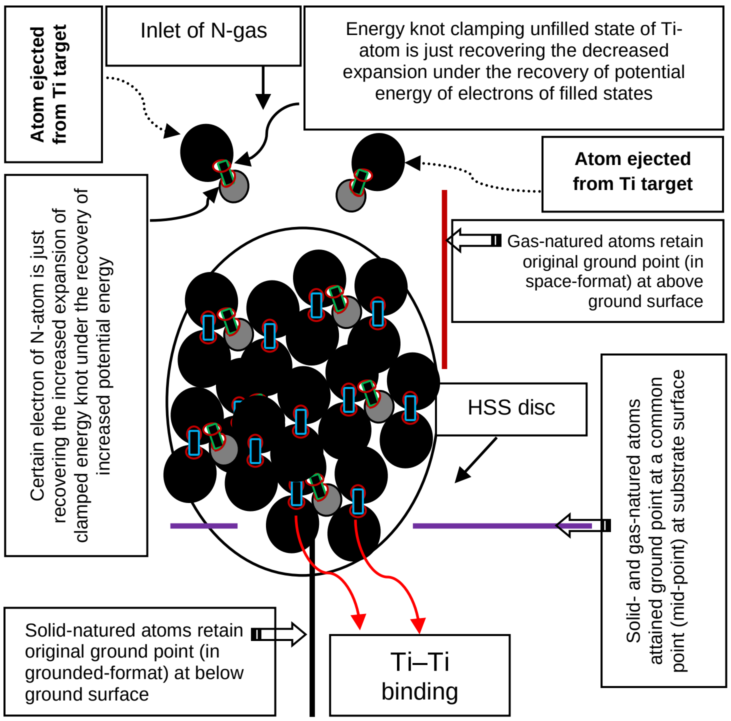

Figure 6: *Mechanism of double clamping of suitable energy knots (of solid-natured atoms) to suitable electrons (of gas-natured atoms already clamped by their energy knots) along with mechanism of binding atoms in Ti–Ti*

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 the surface of the substrate. Solid-natured atoms in original state behavior keep orientational gravitational force to the maximum extent, which is due to their ground points in grounded-format where their electrons undertake fully gravitized behavior. So, their electrons gain the maximum potential energy where clamped energy knots remain in their maximum expansion. So, energy knots constructing unfilled states in those atoms also expand maximally. But, gas-natured atoms when in original state behavior keep their orientational levitational force to the minimum, which is due to their ground points being above the ground surface (in space-format) 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 gas-natured atoms also remain in their maximum level of contraction because of their mutually adjusting contraction-expansion behaviors.

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. 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) is being visualized by a certain unfilled energy knot of a more-expanded landed Ti-atom (where it is pointing toward the upward-side) binds under the minute difference of their ground points. This results into 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 being visualized (for experiencing force) through certain unfilled energy knots of Ti-atoms. This visualization of the unfilled energy knot (of solid-atom) by electron (of gas-atom) to experience the force for tip-sided region is from the rearward-side (back-side of solid-atom). These binding mechanisms of two different-natured atoms (Ti-N) and same-natured 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. 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 to electrons, whereas, in the gas-natured atoms, energy is inversely proportional to the force (levitational) exerting to electrons. Further detail of energy-force (or force-energy) relationship for gas-natured atoms and solid-natured atoms was given in a separate study [4].

The similar sort of mechanism is being anticipated in binding of bi-metallic composition (atoms) when bound to bind to gas-natured atoms, for example, TiAlN. Again, low measured-hardness coating of CrN (compared to TiN) involves the mechanism of binding their different-natured 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, 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 the case of TiCN coating because of the involvement of carbon atom, which requires additional lines to express the science of binding different-natured atoms. Reaction of gas- and solid-natured atoms confirm 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. Developing hard coating is related to involvement of non-conserved energies where non-conservative (frictional) forces are engaged to adhere the structure. However, where the force element is involved first, the energy is engaged as for the 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 wavelength having characteristic of current is discussed [1]. In another study, different types of photons are explored [2]. 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]. A lattice/net of carbon atom is formed by the precisely inter-crossed overt-photons having their certain length and 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 gas-natured atom, which is also recovering from the certain transition state. The reaction of gas-natured atom, when in ground point, which is just above the substrate surface, is at the level of surface-format instead at the level of space-format. This is because of the decreased orientating levitational force of its electrons, where their potential energy is increased also resulting into increase in the expansion of their clamped energy knots. The reaction of metallic-nature atom, when in ground point, which is also just above the substrate surface, is at the level of surface-format as well instead at the level of grounded-format. This is because of the decreased orientating gravitational force of its electrons, where their potential energy is decreased, thus, contraction of energy knots clamping electrons occurs. 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-natured atom (in space-format) and solid-natured atom (in grounded-format) when in their original state behavior. So, their binding under suitably attained transition states engage the force (of both downward and upward) under the involved energies. Hence, their structure acts as a hard coating.

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 substrate surface, thus, they react with N-atoms, which are also just at 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 when under the appropriate coincide where N-atoms are incorporated in their 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 behavior and the decreased plastic behavior, which is also known since antiquity.

To a large extent, a process energy regulates the structure of a hard coating where relevant forces are being engaged to harden it. The process energy maintains the required (transition) states of solid-atoms and gas-atoms to control the potential energy of electrons at the instant of their binding. At instant of binding two different-natured atoms, a gas-atom is not in its original (full) levitation behavior of force, but it is in a decreased levitation behavior of force, where the energy of its electrons is also increased. So, this is an oppositely(nearly) worked force-energy behavior of transitional-state gas-natured atom at the instant of its binding. Same is the case for solid-natured atom but under the directly proportional relationship of force-energy for different-states. Under required (transition) state for solid-natured atom, the potential energy of its electrons is decreased for decreased gravitational force. So, the behavior of force-energy for solid-natured atoms is different to the gas-natured atoms. But, a transitional-state solid-natured atom is also working for its force-energy behavior in a different manner to the force-energy possessed by that atom when in the original solid-state. So, a solid-natured atom under its transition state is also oppositely(nearly) worked in its force-energy behavior.

Certain gas- and solid-natured atoms, when under their suitable behaviors of transition states, are being adhered by the process parameters. Different-natured atoms bind by introducing the mechanism of double clamping of energy knot (belonging to certain unfilled state of outer ring in solid-natured atom) to electron (belonging to certain filled state of outer ring in gas-natured atom). Appropriate vacuum conditions and high power enhance the hardness level 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. Hard coatings also help to understand the behavior of different interacting counterparts. So, they open many new areas of research.

4. Conclusions

In the mechanism of developing hard coating, a gas-natured atom, when in suitable transition state, partially handovers an electron of outer ring to an unfilled state (energy knot) of outer ring belonging to a solid-natured atom, when it is also in suitable transition state. Gas-natured atom binds to solid-natured atom from the rearward-side while attempting to restore original behavior. Here, solid-natured atom attempts to attain its grounded-format. Because of the already attained ground point (in surface-format) of gas-natured atom under desired transition state, it binds to solid-natured atom to be landed at 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-natured atoms and gas-natured atoms are not in their original-state behaviors. They are in certain transition states required for their binding, so, they switched force-energy under the desirable conditions of the process.

The underlying science of developing hard coatings is in the manner that atoms of solid nature perform negative work when undertaking the certain transition state. They attain ground points at the levels above to their originally-attained levels. Atoms of gas nature perform positive work when undertaking the certain transition state. They attain ground points at the levels below to their originally-attained levels. For developing hard coating, gas-natured atoms react with the solid-natured atoms when just recovering from the transition state of decreased orientating levitational force of their electrons. Here, also reacting solid-natured atoms that are just recovering from the transition state of decreased orientating gravitational force of their electrons. Two differently natured atoms bind when they are in desirable transition states where certain electron of gas-natured atom experiences the exerting force to north-sided tip through certain unfilled energy knot of solid-natured atom, on the appropriate coincidence.

Under a common ground point, suitable electron of transitional-state gas-natured atom experiences force to north-sided tip through unfilled energy knot of transitional-state solid-natured atom. Here, gas-transition state atom (and that electron) increases its potential energy under decreased levitational force to gain that transition state. On the other side, solid-transition state atom (and that unfilled energy knot) decreases its potential energy under decreased gravitational force to gain that transition state. This is followed by the tightening of clamp (of unfilled energy knot) to electron (already clamped by own energy knot) under just attempting to regain the force and energy for an instant. This is resulted by the mutual adjustment in contraction (of solid-atom) and expansion (of gas-atom) behavior. This is achieved by the mutual adjustment among energy knots of solid-atom and mutual adjustment among energy knots of gas-atom. Therefore, adjusting contraction of energy knots in the lattice/net of solid-atom (under their collective behavior) and adjusting expansion of energy knots in the lattice/net of gas-atom (under their collective behavior) results into the binding of two different-natured atoms, which is under their oppositely(nearly) working force-energy behaviors.

To deposit TiN coating on a desirable substrate, force and energy of transitional-states gas- and solid-natured atoms work oppositely(nearly) to their original-state behaviors. Certain transition metals govern hard features of coating under affinity to gas-natured atoms because, one is originally related to exerting force in grounded-format and the other is originally related to exerting force in space-format. But, under desirably switching of their force-energy, they attain suitable transition states having ground points nearly in the mid-regions of exerting forces for grounded-format and space-format. So, transitional-state different-natured atoms bind when exerting forces are adjusted nearly for the surface-format. This is being achieved through the supply (involvement) of required-amount energy in a non-conserved manner. Hence, forces of different-natured atoms to attain transition states of binding are by the supply 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 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 (surface), respectively, will result into the unprecedented performances in diversified range of applications. Such strategies can be proven to not only save the revenue but also keep the environment clean. This will help to achieve the unique benefits of coatings and their meaningful utilization. When the application of such coating is for an ultra-precision machining, it can deliver high-performance in the case of dry machining.

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