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NANOSTRUCTURED COATINGS FOR CUTTING TOOLS

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INTRODUCTION:

Recent advances in techniques for the deposition and processing of thin films have enabled the design and manipulation of materials with unique properties that are often unachievable in bulk materials. Improvements unphysical and mechanical properties have been achieved by using nanostructuredmaterials.1 High hardness and toughness are required for machining and wear resistant applications. Hard coatings are essential for enhancing wear resistance and toughness properties of cutting tools. Although conventional coatings provide the above-mentioned properties to some degree, they do not meet the needs of current harsh machining and manufacturing requirements. By engineering composite materials at the nanometer scale, it is possible to obtain super hard materials that rival diamond in performance.2 this nanoscale structuring using nano size grains and Nan layers helps in preventing/pinning dislocations, thereby dramatically enhancing wear-resistance properties. Nanostructured coatings also significantly improve other properties such as toughness and thermal shock resistance of the intended surface for a variety of conventional materials such as ceramics, composites, and metalalloys.3 Along with material properties such as hardness and toughness, other variables including coating thickness, morphology, adhesion of coating to the substrate, geometry, and toughness of the substrate are important in the design of a coating.2

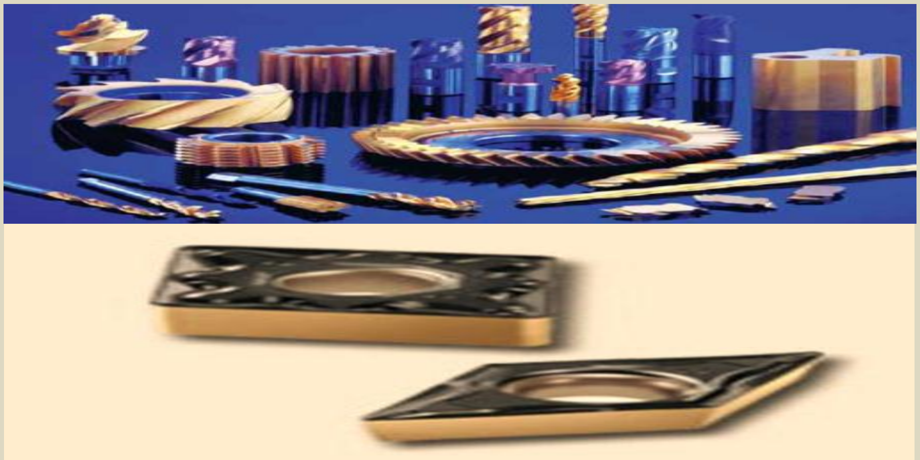
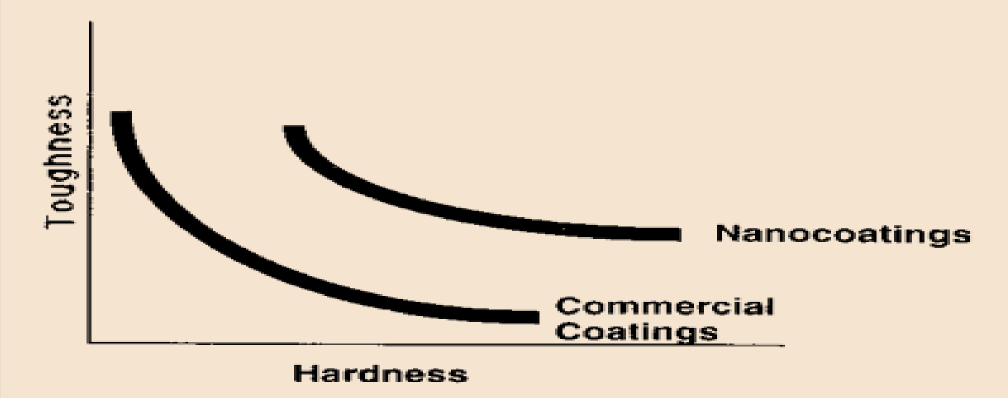


Fig: Coating on Tools

NANOSTRUCTURED COATINGS

Nanostructured coatings are defined as functional materials having features, such as grain size or individual layers, with dimensions less than 100 nm. Nanostructured coatings include metal-metal; metal-ceramic, ceramic-ceramic, and solid-lubricant combinations.4All of these coatings are potential candidates for machining and wear resistant applications. In terms of their nanostructure, coatings can be categorized as nanocrystalline, 3, 5–8multilayer coatings with individual layer thickness of nanometers, 9–12 andnanocomposites.5, 9, 12–15



Figs: Nanocoating

NANOCRYSTALLINE COATINGS

Nanocrystalline metals or coatings display a lower wear rate than their counterparts of commercial coarsegrainedpowders.5,7 This improvement in wear resistance is attributed to the high hardness and toughness of nanostructured materials, and the change of fracture and material-removal mechanism due to ultra fine particlesize.7 For example, the research show a threefold increase in Vickers hardness for nano-nickel particles produced by electro deposition as particle size drops down to the 10 nm range.5 The major challenge for synthesizing nanocrystalline coatings is to retain the particle size of the powders or inhibit their growth at high temperatures. Various methods such as reconstituting nano particles into micro particle “balls” combined with plasma spray have been developed to solve this problem.7

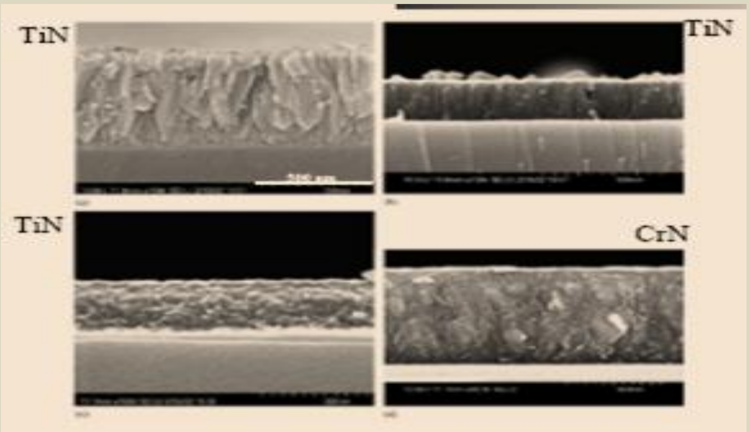


Fig: Nano Crystalline

NANO-MULTILAYER COATINGS

Nanoscale multilayer coatings, which consist of alternating layers of materials, further improve the performance of single-layer nanostructured coatings. The types of materials, their bonding characteristics, and crystal structures differentiate multilayer coatings. When properly tailored, nano-multilayer coatings produce super hardness and super modulus effects.11 Optimum values of mechanical properties can be achieved by varying the number of layers.14 An investigation of multilayer a-C:H film showed a much lower wear rate than its single layer.16

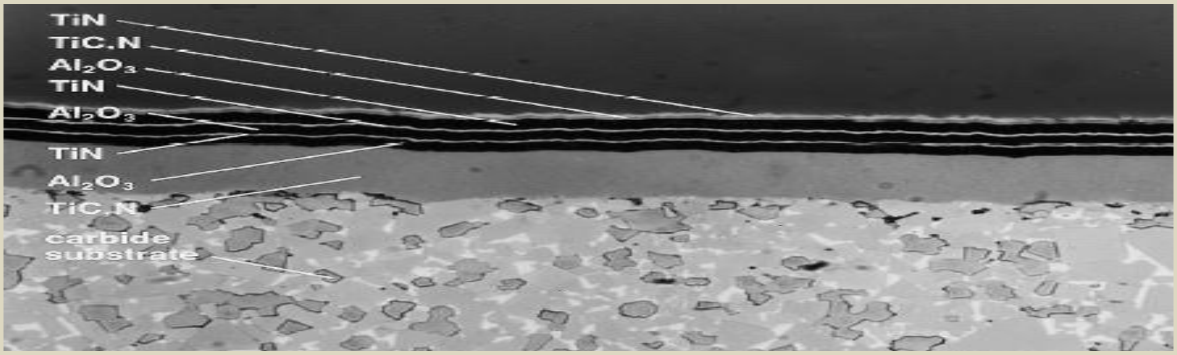


Fig: Multiphase Coatings on a Tungsten-Carbide Substrate

NANOCOMPOSITE COATINGS

In nanocomposite coatings, different materials are combined to achieve new Properties that cannot be obtained from a single material.16 these types of coatings are reported to have improved mechanical and thermal properties. The wear resistance of the nano-Mo/Al2O3was about two times better than that of pure Al2O3 due to the inclusion of nano-molybdenum particles, which efficiently inhibit the growth of the alumina matrix.17 As Figure 1 shows, cutting-tool life increased three to seven times when a sub micrometer and nanocomposite coating of CBN was pre-deposited by electrostatic spray coating (ESC) and infiltrated with TiN by chemical vapor infiltration (CVI).18 The co-deposition of nano-sized ZrO2 in the process of electroplating produced nanocrystalline Ni/ZrO2 composites with increased hardness.5 The design and synthesis of multilayer nanocomposite Coatings of Ti/DLC, TiC/DLC, andCN/DLC significantly improved wear life of the coatings.9 However, Stewartet al. found that nanocomposite coatings of WC-Co had poorer wear resistance than conventional coatings in all testconditions.19 The inferior wear resistance could be explained by decarburization during spraying and the microstructure formation during splat solidification. The wear mechanisms in nanocomposite coatings are different. While the wear mechanism of nanostructured coatings is plastic deformation with slight surface fracture, that of the conventional coating is the initial removal of the binder phase followed by fragmentation of carbide grains.3 SYNTHESIS TECHNIQUESA variety of modern coating technologies have been employed to realize nanostructured coatings.12 These technologies include well established physical vapor deposition (PVD),6,7,13,15,20–23chemical vapor deposition (CVD),3,16,17,24and several other nonconventionalprocesses.10,25–32

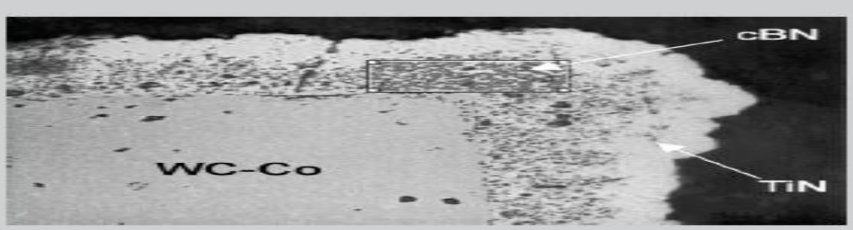


Figure 1. A combinatorial coating of cBn in TiN matrix.

Fig: Nanocomposite Coating

PHYSICAL VAPOR DEPOSITION

Physical vapor deposition is a process in which materials in a vapor state are condensed to form a solid phase. The PVD coating concept is well established in industry, and has shown great potential for designing new thin films with tailored material properties. Stuberet al.14 reviewed the development of tailored coating concepts for PVD deposition of multifunctional coatings. Jesen et al.20 produced a nanostructured multilayer coating of TiN/C-N using reactive sputtering (radio frequency[r.f.] mode)27 with so-called side-side configuration. Ribeitro et al.21 deposited(Ti, Si, Al) N films by using a d.c .reactive magnetron sputtering technique and found that magnetic field strength affected ion current density in the substrate, and consequently, the film properties. Mikhailov et al.22 synthesized metallic and MoS2 nanometer-scale multilayer composite with chromium as an adhesive layer by r.f. magnetron sputtering. PVD methods offer very uniform thickness, good control over the stoichiometry, relatively low deposition temperature, and the simultaneous coating of the entire object. However, these methods have relatively low

deposition rates, high internal stresses in PVD hard coatings, which limits the thickness of the coatings,10 and poor adhesion to substrates.

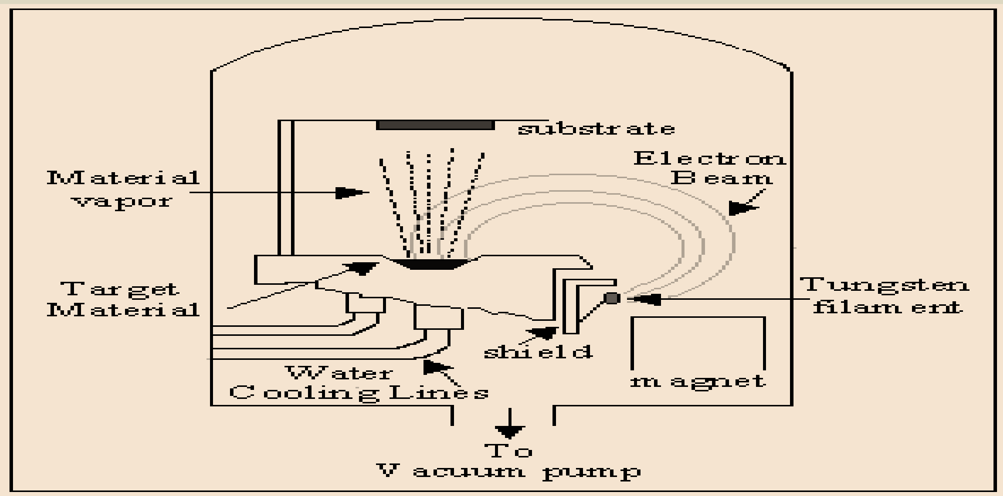


Fig: PVD Coating

CHEMICAL VAPOR DEPOSITION

A typical CVD process consists of two major steps: the vaporization of precursor molecules and transport of those molecules into a reactor, and diffusion and adsorption of the precursor molecules to the surface. This process is widely used for depositing protective coatings on a variety of materials. In et al.17 reported the processing of nano-Mo/Al2O3 composite using metal organic CVD. Bertran et al.3synthesized nanostructured ceramic coatings containing silicon-carbide nano particles by plasma-modulation CVD. This method provides the possibility of designing new structures with the controlled parameters to study the friction, hardness, and propagation of cracks and wear resistance. Fu et al .deposited diamond coatings on pure titanium by microwave-assisted CVD to improve the tribological properties oftitanium.24 The advantages of CVD are uniform thickness and relatively high deposition rates. However, the high temperature in the CVD process leads to grain growth, resulting in the loss of some of the peculiar properties of nanocrystalline materials. Also, CVD is relatively difficult to control due to multiple process variables involved.

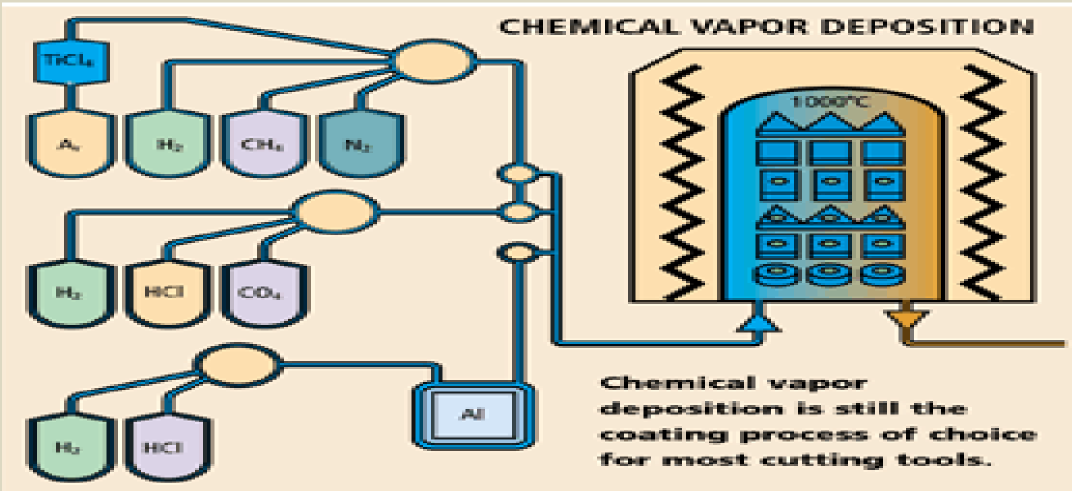


Fig: CVD Coating

OTHER NON-TRADITIONAL PROCESSES

Besides the two most widely used coating processes, researchers have also been investigating the possibility of other synthesis technologies. Rao etal.25 synthesized nanostructured SiC films with grain sizes around 20 nm by a process known as hypersonic plasma particle deposition (HPPD).In this process, nanoparticles are both synthesized and deposited, which results in extremely high deposition rates. In HPPD, vapor-phase reactants are injected into thermal plasma and allowed to pass through the nozzle. The rapid cooling in the nozzle region drives the nucleation of nanoparticles. These nanoparticles are then accelerated toward a substrate by the hypersonic free jet from the nozzle and form a dense nanostructured coating. The advantage of this method is that it retains the grainsize.25,26 A further increase in density can be achieved by using post-deposition processing methods such as sintering.26Milani et al.27 used a supersonic-cluster beam-deposition technique to synthesize carbon thin film. Taylor et al.28 reported their work on nanostructured oxide coatings made by wet-chemical techniques. In another novel approach, Russell etal.29 used a two-step process of ESC and CVI to deposit sub micrometer to nanocrystalline combinatorial coatings of cBN and TiN. Electrostatic spray coating of cBN forms a continuous porous conformal layer over a tool insert. In chemical vapor infiltration, which is a derivative of the conventional CVD process, TiN is infiltrated through the porous medium to form verydensecoatings.29 such a hybrid approach opens the opportunity for novel combinations of nanocomposite material phases. Voevodin et al.30 recently reviewed the publications on pulsed-laser deposition (PLD) of diamond-like carbon coatings for protection against sliding wear. Hydrogenated and non-hydrogenated diamond-like carbon (DLC) films deposited using PLD were investigated by Malshe et al.31,32 Ziegele et al.10introduced a laser-induced vacuum arc (laser-arc) process, which allows good control of PLD and high efficiency of vacuum, for deposition of DLC and metallic nano-multilayers. This process is reported to offer the possibility of overcoming the problem of hard PVD coatings, and, in general, yields better adhesion to a substrate.2 In addition, the process produces a graded interface, and therefore, lowers stress on coatings and improves adhesion. A major drawback of laser-assisted deposition is the high capital cost of the lasers. In addition, low substrate temperature may be responsible for poor adhesion and low deposition rates in certain cases. These problems can be overcome by using higher substrate temperatures and by deploying laser assisted processing. Preconditioning the substrate, for example by lasers or ion beam, and the presence of a magnetic field during laser processing is observed to give better adhesion.

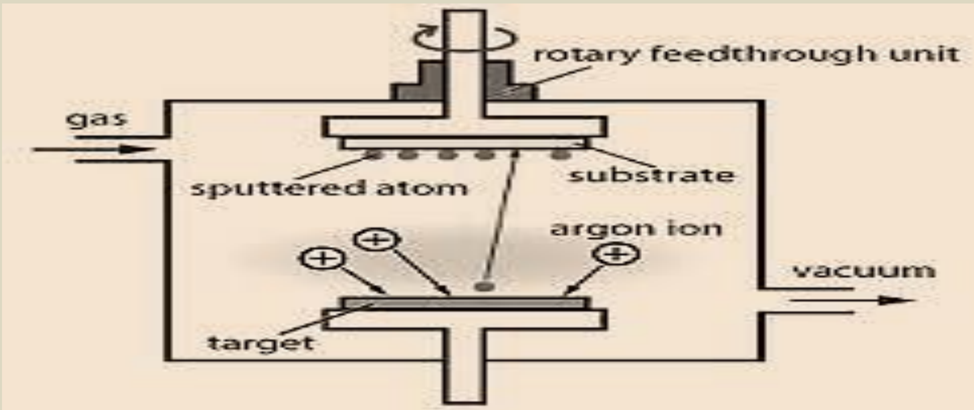


FIG: a

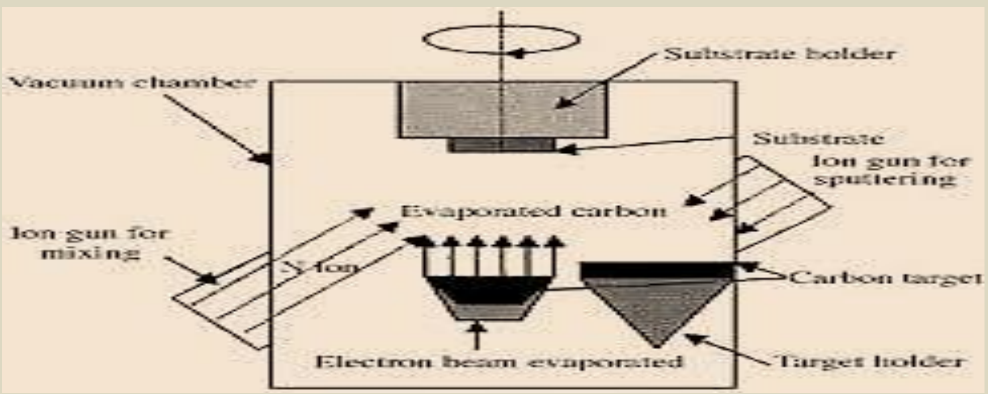


FIG: b

Fig: Ion-Beam deposition

APPLICATIONS

In tools, nanostructured coatings offer improved durability and performance over conventional tools. Their ability to retain a crisp cutting edge makes them ideal candidates for machining. Nanocomposite coatings of alternating nanolayers of hard phase and solid lubricants are being explored for environmentally friendly dry machining. The superior mechanical and physical properties of nanostructured coatings make them well suited for extreme operating conditions such as aerospaceapplications.13 Nanostructured films are being increasingly used in micro electromechanical system (MEMs) devices due to their superior friction and wear resistance, which are the major limitations for MEMs.26

CONCLUSION

The significant potential of nanostructured material combinations is virtually unexplored. There is a great possibility that combinations can be found that exhibit super hardness while also possessing other excellent wear properties, such as high hot hardness, fracture toughness, chemical inertness, and low coefficient of friction. Along with boundless opportunity, there are also numerous challenges to face and overcome. A fundamental understanding of deposition parameters and the nanostructure-mechanical property relation is needed for grain sizes ranging from one nanometer to continuous films of nanoparticles. Understanding different deformation mechanisms and the role of interfaces present at nanometer scale would help in designing better materials.

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