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# A Short Review on PVD technology used for coated cutting tools

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**ABSTRACT**
Nowadays more and more industries are moving towards the PVD technique but there are many different types of PVD techniques used in the industries, and in recent decades this technique is widely used for the coating of cutting tools and has many industrial applications. But the thing is there are many different kinds of PVD techniques used in the industry for coating, so this paper highlights the PVD technique that is most suitable for the coating equipment, that includes cathodic arc evaporation and magnetron sputtering and their hybrid technique. Concerning hard coating deposition on the coating tools, the basic configuration principle, cathode uses, and properties of the coating are also highlighted in this paper. Also, a comparison of this technique with other deposition techniques like CVD, and PACVD are conducted to find which one is better. Finally, this paper reviews thedifferent techniques used in PVD technology and summarized which is most efficient for the coating.

**KEYWORDS**: PVD, Cathode arc evaporation, Magnetron sputtering, CVD, Hybrid technique.

## I. INTRODUCTION

Whenever there is a process of cutting, tools experience a large amount of stress and strain which causes the heating of tools, which can lead to the wear of the tools. That is the reason why coated cutting tools are often used in the industry and these tools are prepared by a different kind of deposition live PVD, CVD or we can say the process is categorized into two types which are sputtering and evaporation [1]. The coating reduces interaction and friction between the tool and the material that increases the lifetime of the tool. The deposition takes place when the coating element evaporates into atoms or ions in the vacuum chamber and is condensed on the surface of the tool. This technique has gained a lot of attention in the recent decade due to its application in industry as well as in research. Now both the techniques PVD(Physical vapor deposition) and CVD(Chemical vapor deposition) are used in the industry and among both the techniques CVD has a good deposition rate but still, PVD is mostly used in the industry the reason is that CVD requires higher temperature then PVD due to which it can affect the tool performance so it is used mainly for inserts and not on cutting tools, and another reason is the chemicals which are used are volatile and after the reaction, it can cause harmful gases [2-4]. So, considering all the parameters PVD is mostly used in the industry.

In the physical vapor deposition method, we can deposit single or multi-layer coating and in some cases hundreds of layers. The technique which is used in PVD is magnetron sputtering, cathodic arc evaporation, and their hybrid technique. There are very few industries that use the hybrid process due to a lack of research on the topic. This paper provides a review of PVD, CVD, and their hybrid and is organized as follows. In the first section, we will see the physical vapor deposition technique in which along with the cathode arc evaporation and its principle, coating technique, vacuum, and magnetic field. In the next section, we will see CVD (chemical vapor deposition) technique used for coating. The first section explains the physical vapor deposition technique along with the cathode arc evaporation, it also has a brief explanation of working principle, coating technique, vacuum field, and magnetic field. The next section will be continued with CVD (chemical vapor deposition) technique used for coating. The third section is all about the sputtering technique used for the coating and the main principle behind this technique, and has an explanation of the theory with the help of the diagram. And followed by the target power supply, dielectric coating and reactive sputtering

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techniques. The fourth section will cover the hybrid process for coating including the relationship between the deposition rate and degree of ionization, and also cover the different changes in deposition rate which will be further compared to degree of ionization, ionization ratio of metal and gas. And in its last section, the paper wraps up with the conclusion.

## II. PHYSICAL VAPOR DEPOSITION

Physical vapor deposition is the process in which a metal coating is deposited on different kinds of tools that are used in the industries and are done in the presence of the vacuum the basic principle in this is that cathode is deposited on metal surface in presence of vacuum. There are many different kinds of PVD (Physical vapor deposition) techniques available for coating some of them are cathode arc, magnetron sputtering, electron beam, and the hybrid of cathode arc and magnetron sputtering among this cathode arc and magnetron sputtering are the most used technique for deposition of the coating on a metal surface [5]. The PVD process differs for every different kind of evaporation of components. The deposition of the metallic component from a solid to a vapor phase where metal molecules are ionized differently.

### 2.1 Cathode arc evaporation

The cathodic arc evaporation (CAE) also known as arc ion plating (AIP), has the principle of vacuum arc depositions. The arc evaporation has high current and voltage discharge which is a plasma discharge. And this starts between the cathode target which is made of evaporating material and the anode which is biased in the vacuum chamber [6]. In the process, the cathode is evaporated and condensed on the substrate surface. If the magnetic field is not present in the vacuum chamber, then the cathode particles will move randomly over the surface.

An increase in the energy density will lead to the transformation of the solid material which is the main target at the arc spot to the metal vapor, alongside droplets that are large in numbers [7].The melting temperature of the target and the droplet are related has the ejection of droplets that take place and condense into macro-particles and after that, it deposited on the coating surface which results in a rough surface, because of this overall performance of the coating is significantly reduced and this is the biggest issue faced in this technology.

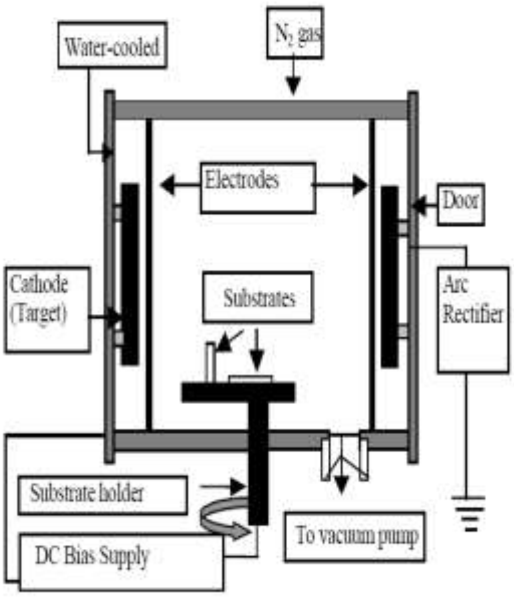


**Fig 1. Schematic diagram of the Cathodic Arc Evaporation (CAE) PVDTechnique.[7]**

#### 2.1.1 Configuration of cathode

If the cathode configuration is optimized it can result in a reduction in the generation of droplets. Cathode evaporators can be characterized based on the geometry and the essence of the movement control of the arc feed. There are many commercial applications of cathode geometrical used in the industry which are rectangular, cylindrical, and circular planar targets. As we already know that power supply for cathode arc

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evaporation uses a high density and low voltage current power supply due to which the material surface is connected to a highly negative power supply. And since electrons, as well as ions, are easily controlled with the change of electric field and magnetic field, in many case studies they are experimenting to control the generation of droplets using optimizing cathode target power supply [8-10]. For a certain level generation of droplets can be reduced by the technique of pulsed arc ion plating and during the process of deposition very high current is used and discharge is pulsed to provide a certain time to conductive particles.

So now the formation of microparticles is highly limited due to less time required for the generation of the droplets and that is due to less time in pulse-on time and because of it, the high deposition rate is achieved in the industry. In many studies, the values of current and voltage are taken as the arc deposition with a voltage of 28-30kv and a current of 3-5kA [11]. This technique of Pulsed vacuum arc deposition has proven to show many advantages in the formation of hard films in a large area and mostly shown the result in carbon coatings [13]. The only problem this process showed was the discharge stability.

The history of the process starts in the mid-90s the name of the process was given a modified pulse arc evaporation in which there was combination of two different techniques to increase the stability of any condition for example increases in velocity post at low current supply. Even after that many case studies were conducted to increase target absorption and to reduce the numbers of microparticles due to which the quality of coating increases [14]. And due to this there is an increase in the diamond-like coating in the industry and discovered that the magnetic field can be generated by itself. When compared with the electric field, the magnetic field shows outstanding performance in influence on the plasma vacuum arc.

The crosswise magnetic field on the target surface advances the cathode spots motion in the deteriorating direction, and then by the change in the magnetic field or by increasing the magnetic field, we can change the velocity which will increase with an increase in the magnetic field and if this condition is satisfied there will be a reduction in time as well as the macroparticles [15]. When the axial magnetic field is introduced in this there is a change in the motion of the cathode spot and it becomes a hybrid process, it becomes a completely new process and is indicated as steered arc process. So, this axial magnetic field has a suppression effect on the plasma loss. It is said that the transverse and perpendicular magnetic have the main role in the arc stability and high the axial magnetic field increase the distribution of the cathode.

### 2.2. Magnetron sputtering technology

The basic principle of magnetron sputtering technology is shown in fig 2. The magnetron sputtering is a well-controlled process in which the cathode target is aflame by energetic ions which are generated in a discharge plasma vacuum chamber, increasing target particles [16]. The Magnetic field which is denoted by **B** forces electrons on a circular trajectory as a result continuously increases the residence time of electrons in the plasma. In the magnetic field, ions don't undergo any changes due to their weight, as we know that ions are heavier with compare to electrons. This increases the chances of collision between electrons and the argon gas atoms and increases the ionization of gas molecules. When the electric field is applied in the process the gas ions start to accelerate and spreads the target particles throughout the surface and condensed on the surface resulting in a hard and smooth coating. This when compared to the cathode arc evaporation the magnetron sputtering shows a significant result, the temperature required is low. When this condition is satisfied ionization ratio of the molecules decreases significantly and limits its application [17]. But to overcome this condition more plasma is used in the industry and is given the name of plasma enhanced magnetron sputtering technology, as a result, the performance of coating increases significantly.

#### 2.2.1 Magnetron sputtering

Another method for physical vapor deposition is Sputtering or magnetron sputtering, in which instated of nitrogen, argon ions are used for bombarding it on cathode connected target made of the coating material. High energy ions help atoms to hit the target and deposit it on the substrate surface for coating. Magnetron sputtering is the method where direct current sputtering is enhanced by the electrical field and crossed the magnetic field and due to that high-density plasma is formed in the region conjoining to the cathode surface [18]. The magnetic field which is formed inside the reactor is produced by the magnets installed beside the target and due to the magnetic field, the electrons travel differently. The electrons travel in a spiral trajectory in the plasma field. While traveling the electron collides with the atoms of the argon producing more and more numbers of ions with compare to the basic DC sputtering technique. If

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there is a need for a higher deposition rate then an increase in the density will do the work, as higher the density more collision will occur which increases the rate of deposition. Even in the case of heating, this technique provides lower heating, since the plasma is near the cathode ions of argon and is unable to reach the substrate.

The deposition rate of magnetron sputtered for hard coatings decreases for a certain condition, with an increase of N2 partial pressure the deposition rate decreases [19-21]. This decrease in deposition is caused by increasing coverage of the target and this is done by absorbing nitrogen gas of the target or we can say nitridation of the target. The phenomenon is called target poisoning. This magnetron sputtering technique was modified several times, the reason was to increase the rate of ionization and for deposition of hard coating at a faster ionization rate the requirement is a higher ionization magnetron sputtering method. For overcoming the problem faced in the cathode arc evaporation magnetron sputtering was

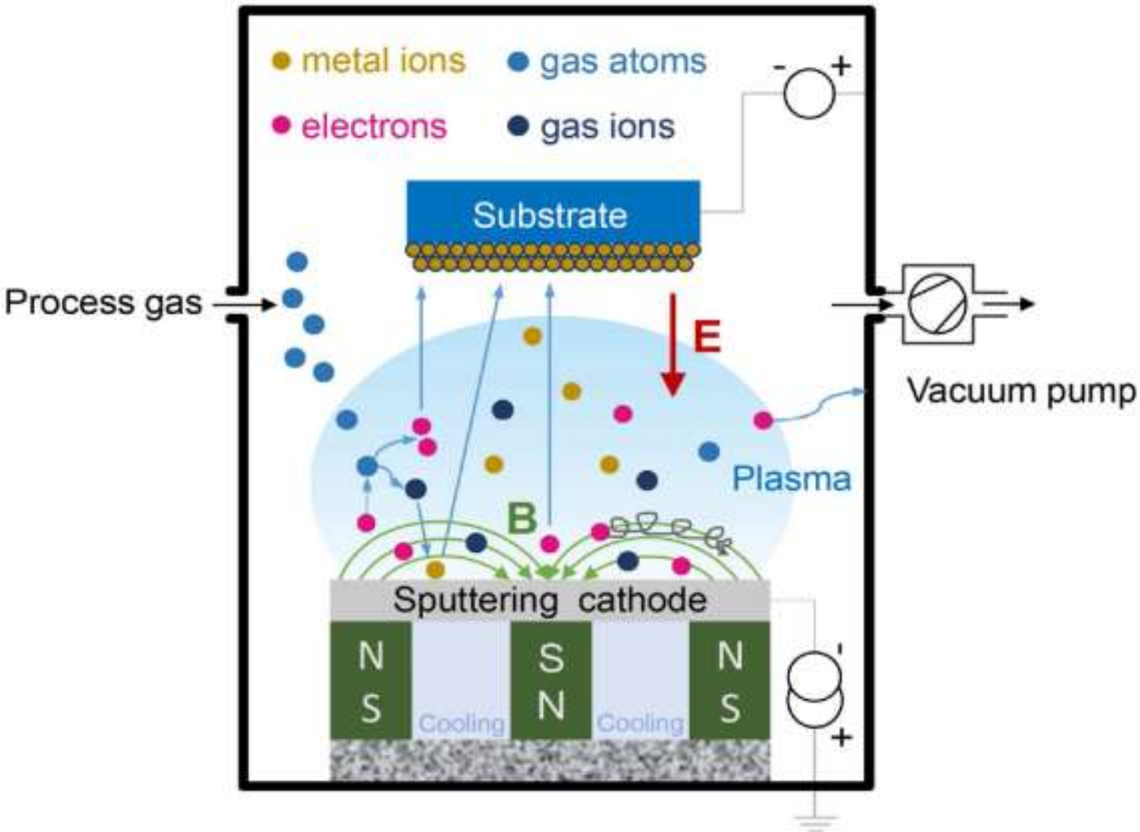


**Fig 2**. **Principle of magnetron sputtering technology.[18]**

used because this coating has a circular structure, as well as the surface, was smoother without any microparticles present on the surface.

Sometimes the target acts as the cathode during some time when the cycle is started, this happens when the positively charged electrons of plasma travel to the electrode and negatively charged argon ions move rapidly towards the surface expect this case, the rest of the time cycle acts as an anode. Electrons are lighter in comparison with the ions, so the speeds of the electrons and ions are different due to the difference in their masses. The basic principle is lighter the molecule faster is the speed;thus, the electron reaches the target surface faster than the ions due to which the anode has a shorter duration with compare to the cathode which is positively charged. In this case, plasma acts as a recovering agent producing a negative voltage that causes an increase in the targets of the ions and collides with the molecules resulting in the molecule settling on the substrate surface and forming a hard coating [22].

**2.2.2Magnetron configuration**

Magnetron sputtering is a method where the magnetic field is used and this magnetic field is trapped inside the chamber which is also known as the trapping effect, due to which the ratio of ionization and rate of coating deposition increases with low temperature. Fig. 3 [26]. In the magnetron sputtering magnetic field controls the transmission path of the plasma, the magnetic lines which are formed come from one end of the target to the other end of the target (namely balanced magnetron, as shown in Fig. 3(a)). Sometimes the coating surface can be condensed by a very little amount of energy particle this is because of the transmission path of plasma which is based upon the magnetic field present, due to which amount of plasma will be more and that will result in a decrease in efficiency in the production, and this method was also named by balance magnetron.

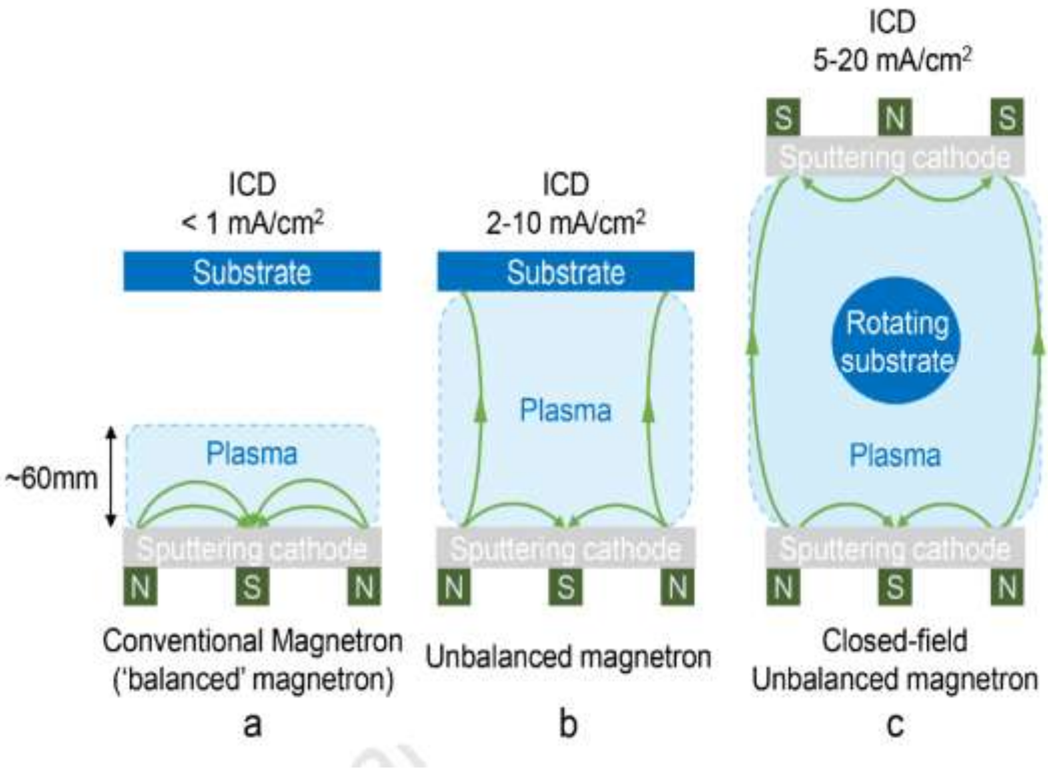


**Fig 3. Different types of magnetron configurations.[26]**

Similarly, the concept of unbalanced magnetron sputtering was introduced where the ion current density of the substrate is higher with compare to the balanced magnetron, and few magnetic lines were formed in the direction of the substrate. There are some techniques by which some changes can be done to the balanced magnetron to modify it to an unbalanced magnetron and this can be done using a certain type of magnet that is toroidal in shape, as a result, the deposition rate of the coating increases significantly with compare to other magnetron methods. (2-10 mA/cm2 [23,24]). If there are multiple targets for the coating a different kind of technique is used which is closed-field unbalanced magnetron sputtering.

The sputtering targets are of different types some are cylindrical some are circular and some are rectangular targets. Of the three types of targets generally, the rectangular target and the cylindrical targets offer the largest area for the coating on the substrate surface [27-30].

## III. REACTIVE SPUTTERING

The process of reactive sputtering is done by using a chemical reaction, this chemical reaction is done between the molecules present on the substrate surface and the gas which is used during the process. Reactive sputtering is a process where the concept of conventional sputtering and Chemical Vapor Deposition are applied or we can say it is a combination of both [31]. For the chemical process, the reactive gases which are usually used are Nitrogen and Oxygen and the reaction takes place when the metal molecules

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reach the substrate surface as the target is a metallic target, as a result, the gases (nitrogen or oxygen) molecules deposits on the surface of the substrate forming the hard coating [33].

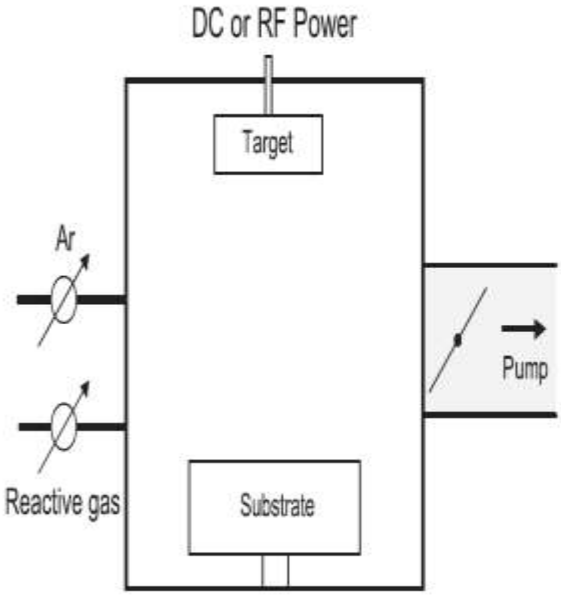


**Fig 4. Schematic of a simple reactive sputtering system.[34]**

The reactive sputtering process has two key factors are

1. A large amount of reactive gas is used for the growing of the film and the rest goes in the downward direction to the pump.
2. Metal sputtering is faster with compared to the compounds; the compounds sputter slowly.

## IV. DIRECT CURRENT (DC) SPUTTERING

Direct Current (DC) sputtering is a basic thin film Physical Vapor Deposition (PVD) technique where a constant voltage which is a DC voltage is used between the substrate and the target material. The substrate is indicated as the anode and the target as the cathode. In simple terms, we can say particle bombardment is done with the ionized gas resulting in the sputtering of the atoms [35-37]. In many cases, the ions which are commonly used are Argon (Ar) ions for bombarding the surface of the target. When the chamber is vacuumed to lower than the average between the 3-9 m torr, an argon atom is introduced into the vacuumed chamber with a direct current voltage of 2-5kv due to which argon ions are ionized to form the ionized gas which is plasma. Argon atom with the positive charge ions moves toward the cathode target which is bombarded to the surface and breaks the atoms at the target.

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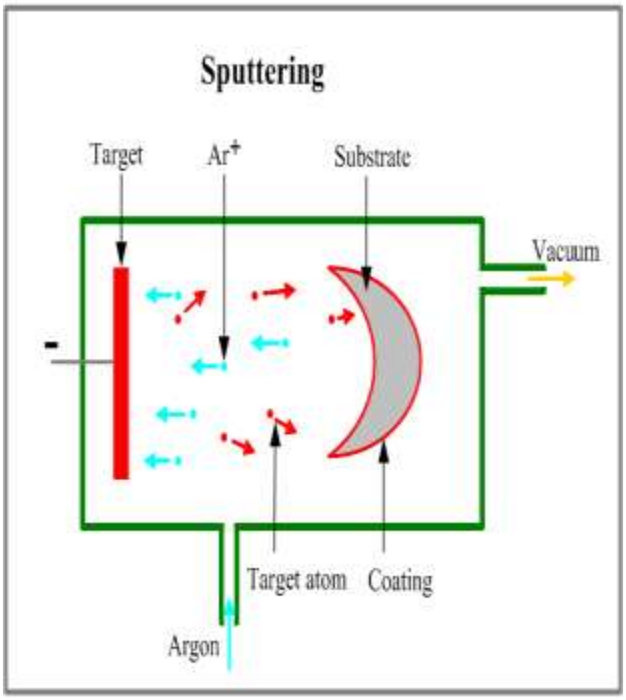


**Fig 5. Schematic diagram of DC sputtering.[46]**

the atoms which are bombarded travel throughout the chamber in a different direction and last is settled on the surface of the substrate resulting in the deposition of the coating. Direct current sputtering is used for the metal deposition and in the process the anode conductivity does not change when the coating deposition on the anode is done on the substrate [46]. So, this technique can be only used when the material is used for a conductive material and cannot be deposited on non-conductive material, this is due to the electron flow towards the anode. The process has many advantages but the only disadvantage is the low deposition rate when the density of argon ions in production is low.

## V. HYBRID PROCESS

We have seen many different kinds of Physical Vapor Deposition techniques used in industry and they have their advantages and disadvantages, so many case studies were conducted to find a new technique where we can use only the advantages of all the techniques present. So, the concept of hybrid technique was introduced and many types of research were done for the same to compensate for the shortcoming of the other techniques. Alongside there are a lot of case studies on the use of different Physical Vapor Deposition techniques to obtain an increase in performance and increase in the layers of the coating [48-50]. Various kind of research has been conducted to study the process of hybrid High Power Impulse Magnetron Sputtering (HiPIMS) and Direct Current Magnetron sputtering (DCMS) technology. DCMS technique ensures the highest rate of deposition as well as stabilization of plasma, and pulse glow optimization through the process of ionization. [51-53]. This kind of technique can improve the properties of the coating in High power Impulse Magnetron Sputtering. [54] Many have done a lot of research in combining the two techniques which are HiPIMS and DCMS by using a machine. As shown in Fig. 6.

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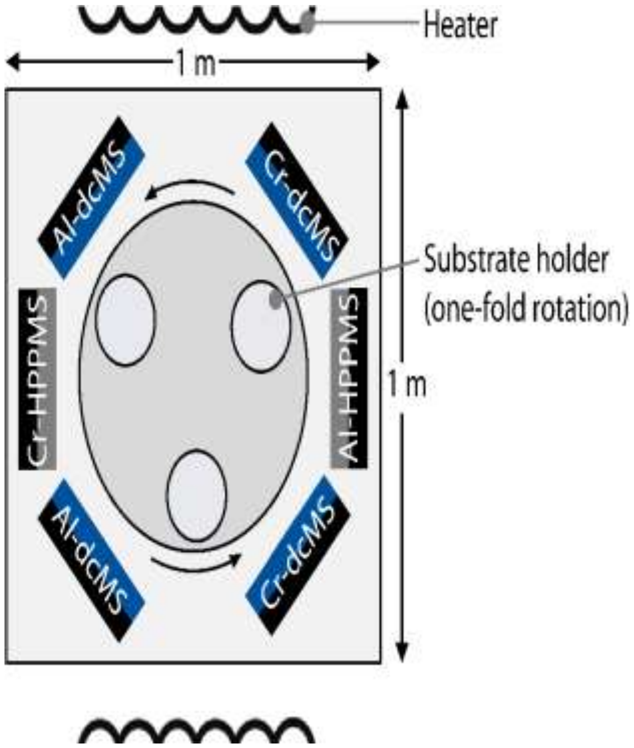


**Fig 6. Schematic illustration of the coating deposition setup (top view).[56]**

This system was designed with four Direct Current Magnetron Sputtering cathodes and two High Power Impulse Magnetron Sputtering cathodes and every cathode installed can work individually [56]. Through this, they discovered that the High-Power Impulse Magnetron Sputtering process greatly increases the ionization process in the metal and gas, resulting in the improvement in the quality, and hardness of the coating and decreasing the surface roughness of the surface. The coating deposition rate of the process was higher when the arrangement of the cathode in HiPIMS and DCMS is at the same position. Research also found various new improvements in deposition rate during the process and irradiation growth of metals ion during the deposition of the coating in the hybrid process of High-Power Impulse Magnetron Sputtering. The process was flexible and separated in the structure and physical properties of the coating. It is also observed that this technique and other pulsed magnetron sputtering have improved deposits rate. [57-59] In a reactive atmosphere, it is found that the hybrid process (High Power Impulse Magnetron Sputtering) and other sputtering technology can reduce the delay between the edge of cathode voltage and current significantly. These results were found in many different case studies. Much research was done on increasing the time of MF pulse which will increase the deposition rate but due to this, the degree of ionization is decreased. Apart from this, there is the hybrid of different magnetron techniques which we have seen in this paper, much new research has been done on the combination of arc deposition and sputtering technology.

In which the high plasma is used for the hard coating in the nanoscale by the hybrid DCMD method. Researchers found the connection between concurrent and magnetron sputtering they discovered that surface poisoning of cathode targets can be observed. The compressive stress is observed on the lower side with the high hardness of the coating. [60]. According to the survey, itis possible to combine the arc deposition with the magnetron sputtering, it analyses the hybrid plasma is activated by closing the arc discharge and also found.Due to this the deposition rate of the coating increases as well as ion density. Hybrid techniques required a large area to filter the arc deposition and the sputtering technique, the unbalanced sputtering technique is preferred over the balanced one. As a result of this, the arc deposition and High-Power Impulse Magnetron Sputtering have many advantages and this technique provides a high possibility for hard coating and multilayer coating [61-64].

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## VI. COMPARISON OF PROCESSES

For the comparison between the different PVD techniques, we will see different parameters for each, a technique like Electron beam, Magnetron sputtering, and Cathodic arc techniques. We cannot rate the techniques just by looking, we can rate them depending on parameters and deposition processes. Table 1 gives an overview of the typical parameters like inert gages, reaction deposition, phases, evaporation tools, the quantity of ionization, and the geometry of the cathode.

| processes | Parameters | | | | | | |
|---|---|---|---|---|---|---|---|
| ………… | Inert gases | Reactive deposition | Additional ionization | Evaporation tool | Phase | Geometry of cathode | Quantity of ionization |
| Cathodic arc ion plating | No | Yes | Not required | Thermal arc | Solid-Vapor | Flexible | 45-100 |
| Anodic arc ion plating | No | Yes | Limited | Electron beam | Solid-Vapor | Flexible | 5-35 |
| Electron beam deposition | Variable | Yes | Aimed | Electron beam | Liquid-Vapor | Limited | <1 |
| Magnetron sputtering | Yes | Yes | Aimed | Sputter effect | Solid-Vapor | Limited | 2-4 |

**Table 1: Typical parameters and quantity of target/cathode ions/atoms of different PVD processes.[68]**

## VII. CONCLUSION

In this paper, we have seen many different types of PVD (Physical Vapor Deposition) methods for hard coating on tools, this paper also includes the working of cathode and anode for different types of PVD techniques. And the type of cathode that was used is the pure metal target or alloy target that is made by metallurgy. The main focus of Cathode Arc Evaporation is to control the microparticles present in the system and this is done by controlling the cathode configuration and filtering system. It has been observed that the deposition rate of coating in microparticle filtering is less in Cathode Arc Evaporation, due to this different cathode configurations are used. That is the reason this technique is widely used in the industry, but in the case where microparticles affect the coating, the technique is not suitable for that kind of situation. On the other hand, Magnetron sputtering shows good results in coating surface quality, increase in ionization ratio, and acting deposition rate. High Power Impulse Magnetron Sputtering technique which is based on unbalanced sputtering is a newcomer but is trending in the research department due to its application in cutting tools for coating. A new generation will need new techniques so further development of current techniques will continue, the techniques as cathode arc evaporating, magnetron sputtering, and pulsed processes. The above paper concluded that there are many different PVD techniques from which cathode arc evaporation shows good results but now sputtering technology is dominating the industries. The hybrid process which is the combination of both arc evaporation and sputtering is the best technique, but it has a long way to go before implementation of it. So, for now, the High-Power Impulse Magnetron Sputtering technique (HiPIMS) is best suited for coating on cutting tools.

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