I-ECO-015: An Energy Star Physical Vapor Deposition (PVD) Machine

A.R. Bushroa[1,5*], N.A. Azmi[1], R. Mahmoodian[1], M. Hamdi[1], N.A. Mardi[1], S.N. Musa[1], Z.M. Noor[2], Wasa. K[3], Hiroyuki Shiino[4], Keiichi Warigai[4], Hafiz Mazlan[4], Vijay Gupta[5]

[1] Center of Advanced Manufacturing and Material Processing, Department of Engineering, University of Malaya, 50603Kuala Lumpur, Malaysia

[2]Institute of Biological Science, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia.

[3]Department of Micro-engineering, Kyoto University Yoshida Honmachi, Sakyoku Kyoto 606-8501 Japan.

[4]ULVAC (M) Sdn. Bhd, No.8 Jalan Gitar 33/3, Elite Industrial Estate Off Jalan, Bukit Kemuning 40350 Shah Alam, Selangor, Malaysia

[5]Mechanical and Aerospace Engineering, University of California, Los Angeles, CA 90095, USA

Corresponding author: *bushroa@um.edu.my*
,mahmoodian@um.edu.my, hamdi@um.edu.my, azizim@um.edu.my, nurmaya@um.edu.my, ashihazmi@gmail.com, alin@um.edu.my, kiyotaka.wasa@gmail.com, hiroyuki_shiino@ulvac.com, keiichi_warigai@ulvac.com, hafiz_mazlan@ulvac.com,vgupta@g.ucla.edu

Abstract

Physical Vapor Deposition (PVD) Technique is one of the most favourable techniques to deposit thin films in the range of Nano scale. However, the current PVD setup in the market has several deficiencies. The normal size of the PVD is relatively large and this will require larger parts and devices to build the system that contributes to a larger space to locate the equipment. The target used (i.e. The source of the atom to be deposited as a thin film) in the conventional method is normally in the solid form. Target of ceramic, a combination of more than one element, inorganic or powders could not be sputtered using the conventional method due to the unsupportive design of PVD. The conventional PVD for lab-scale usage could be improved by the innovative design of magnetron sputtering that utilizes the concentration of electrons to enhance the plasma ionization. The design highlights the arrangement of magnets to capture and entrap electrons for better ionization rate. This knowledge is transferred to ULVAC (M) Sdn Bhd to be embedded into the conventional lab-scale PVD to enable the sputter of powders. Since sputtering the powder and its mixture is relatively easier and efficient in this PVD system, the technology will enhance innovative and creative formulation of various thin film depositions for different properties. This innovative technology is seen to address issues of industrial related community to find new ideas for improved properties of thin film and its application and to reduce costs.

Keywords: *PVD, Thin Film, Magnetron, Powder Sputtering*

1. Introduction

Physical Vapor Deposition (PVD) coating system has been receiving special attention because they possess interesting properties like most coatings that have high temperature, good impact strength, excellent abrasion resistance, environmentally friendly. Furthermore, the system has more than one techniques that can be used to deposit thin film (Audronis et al., 2005; Mattox, 2010). They are becoming promising for numerous applications that can be benefited in industry like coating material, decorative coating, electronic, recreational equipment, medical implements, aerospace and automotive (Wang et al., 2003; Wasa, 2012)

In recent years, there has been a surge in demand for high-precision processing, mainly from the semiconductors and the next generation micro-manufacturing, aerospace and electronics sectors. The formation of thin films, a surface layer with a thickness of a few micrometers, falls under this category of high precision manufacturing. These films have properties much different than that of bulk materials or that of the substrate on which the film is deposited. There are a variety of techniques for thin-film deposition, generally referred to as vapor deposition processes. Depending on the source of the vapors to be deposited, vapor deposition process can be classified as physical vapor deposition (PVD) or chemical vapor deposition (CVD) (Audronis et al., 2006). Amongst the two, PVD technique is more widely used for thin-film formation. Here, vapors are produced using resistive heating, atomic sputtering, ion plating, magnetron sputtering or lasers, alone or in combination with each other (Rumaiz et al., 2000).

Sputtering processes are widely used in PVD deposition by virtue to their easiness in composition control or device operability. Sputtering is a mechanism by which atoms are dislodged from the surface of a material as a result of collision with high-energy particle. In the PVD sputtering process, the atoms or molecules are ejected from a target material by high-energy particle bombardment so that the ejected atoms or molecules can condense on a substrate to form monolayer of atom or thin film (Kelly & Arnell, 2000). For most cases the target material is in a plate-shaped (disc-shape) solid metal element, alloys or ceramic compounds. Another problem associated with solid disc based targets is the efficiency of the depletion process during sputtering. A major issue is the difficulty in obtaining in-plane uniformity in the deposition rate and the formation of a stable film deposition. To overcome this limitation, some researchers has proposed penetrating techniques using powdery or granular targets (Yamashita et al., 2005; Yumoto et al., 2015).

Amongst the PVD techniques, magnetron sputtering takes the major role. However, commonly observed drawback of this technique is that the sputtering phenomena normally take place from a solid plate, known as the target, of the material to be deposited. The solid target can only be prepared in compacted bulk solid which is difficult to be fabricated. Thus, to fabricate the target in solid forms, in particular for composite or ceramic based materials, the concept of utilizing non-compacted, powder target for PVD was required (Audronis et al., 2006). Deposition of monolayer coating having more than one phase and composed of more than one element and multilayer coating also will be a challenging task to be achieved using said type of PVD machine. This is not only inconvenient, but also very expensive. The advantages of preparing targets in the current proposed way are that any material that is available in powder form can be considered (Braeckman et al., 2015). This approach offers great flexibility for effectively depositing a uniform coating on a substrate. Prior to industrial problem, the existing PVD machine contributed to increase energy consumption and need a larger space to locate this machine.

Thus it can be seen that there is a tremendous research and commercial potential for the development of a PVD process which can directly utilize targets in the form of powders. This work represent the first steps in the process of invention, discovery and development of a new physical vapor deposition technique, termed powder based physical vapor deposition (PPVD). This technology has been envisioned to be the method of choice for depositing compound, multi-component and functionally graded multi-layer thin films from blended powders.

Previous research has documented that coatings were fabricated by sputtering loosely packed blended powder targets as an effective alternative to the problematic sputtering of solid boride targets. This approach has been successfully used for the deposition of chromium boride films by Audronis and colleagues (Audronis et al., 2005). The powder blend was mixing appropriate quantities of purity chromium and amorphous boron powders to have a 1:2 atomic ratio of chromium to boron in the target. However, the choice of pulsing parameters in terms of deposition rate and film stress is an important factor in determining the film properties. This article also introduces a new invention by installing a water-cooled substrate holder in order to overcome the coatings peeled off during deposition because of the high substrate temperatures.

Recently, an existing PVD coating machine has a few problems especially energy consumption in industrial usage. The increases in energy consumption are due to supplies of power for the industry which operates 24 hours. Based on the energy calculation, each machine spends 24,192 kWh per year (RM 9,120). However, for our proposed PVD coating system the energy is saved up to 25% for energy efficiency. This improvement would provide energy efficiency that could only be attained with the best available technology and practice. This means the industry sector will spend more utility expenses. In terms of dimensional aspect, most of the existing PVD coating machines are bigger in size. This requires a bigger space in to locate this machine. However, the proposed PVD coating system is compacted up to -41.6% compared to conventional one. This will definitely reduce cost for assembly, material handling and packaging.

This competitive proposes PPVD system can be employed to coat certain material for certain application. The functionally graded layer, Nano-composite and chameleon coating are enabled for this coating system for applications such as automotive, machining, cutting, biotechnology, etc. Therefore, it is believed the new PVD coating system will strengthen Malaysia as a technology provider in the key strategic knowledge industries such as biotechnology, advanced materials and advanced manufacturing.

The basic aim of this project, therefore, was to provide an alternative to conventional method of physical vapor coating system by using powder. The relevance of the present PPVD machine relates to the need of new technology of sputtering system for energy saving and reduction in hazardous chemical usage. This paper proposes a new approach to be a global leader in a Surface Coating technology with a trade name of an Energy Star Physical Vapor Deposition (PVD) machine. Accordingly, it would therefore be desirable to provide a physical vapor apparatus that comprises of an alternate magnetron cathode to allow sputtering of powders of metal and/or ceramic material, which ables to overcome the problems existed in the prior art.

2. Transferred Technology to ULVAC

2.1. Basic platform of PVD for powder magnetron sputtering

ULVAC (M) Sdn. Bhd is one of the SME'S manufacturers of the PVD coating system in Malaysia. The company's mission is to supply products of the highest quality by minimizing energy consumption and industrial waste. Problems are faced in finding an appropriate alternative coating technology that would offer the best quality and cost-effective production coatings according to the available standard. Thus, technology regarding on the magnetron sputtering is transferred to them to be employed into the conventional lab-scale PVD to enable powder sputtering. Since sputtering of the powder and its mixture is relatively easier and efficient in this PPVD system, the technology will enhance innovative and creative formulation of various thin film depositions for different properties. A new invention for Physical Vapor Deposition apparatus was designed that had alternate configuration and a modification of magnetron assembly equipped with a customized vacuum chamber. The apparatus has predetermined specification to allow sputtering of powder of metal and ceramic material in monolayer deposition as well as multilayer deposition. The design of this machine will be composed of two major components, namely the PPVD machine with powder target and the high temperature controller operating in the range of 100 º – 700 ºC. This high temperature controller is a significant improvement to the existing temperature control system which can only operate up to a maximum temperature of 400 ºC. It is expected that this high temperature controller, integrated to the newly developed PPVD machine, would enable the deposition of piezoelectric complex oxides such as PZT and PT and end-base ceramic materials.

The new invention presents a physical vapor deposition apparatus for depositing substantially uniform coatings on a substrate includes preferably a powder of a

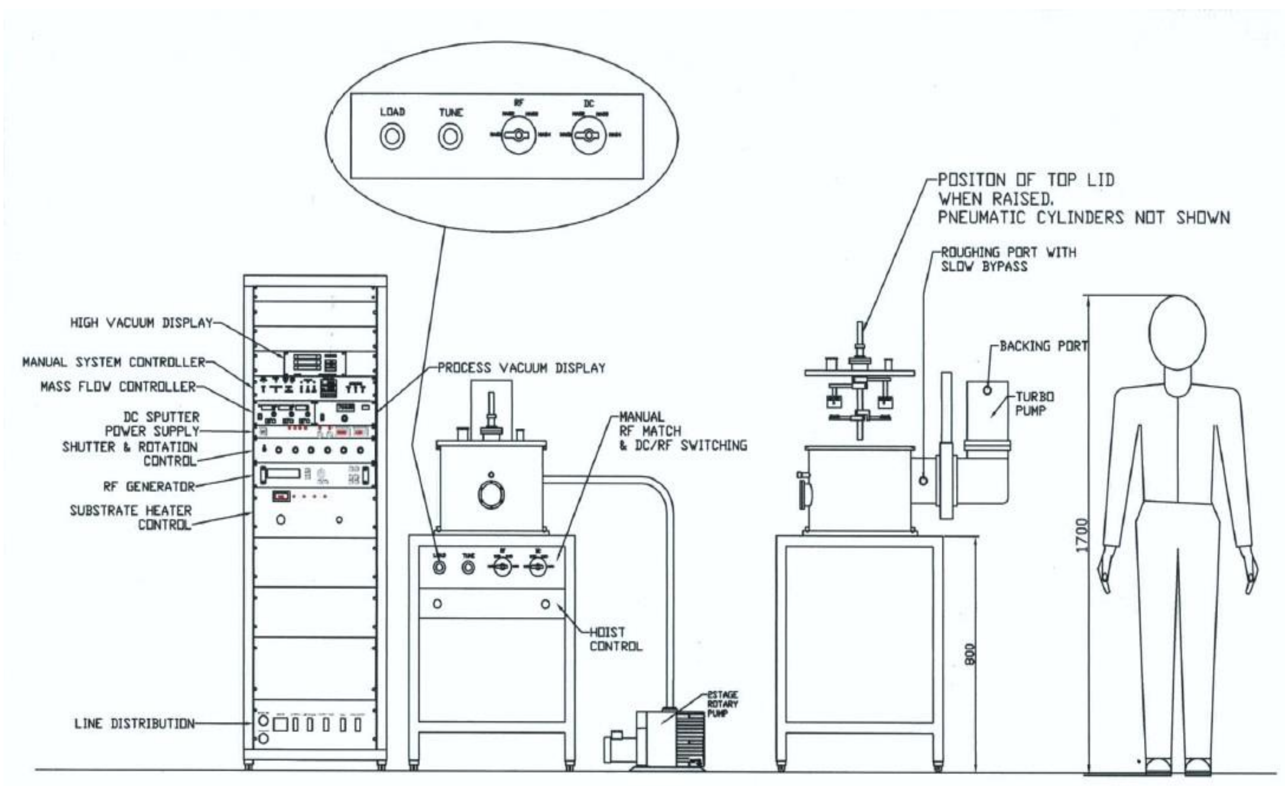

Figure 1: Schematic of basic platform of powder magnetron sputtering system.

metal or a ceramic material. This machine comprises of:

1. A deposition chamber,
2. A rotary shaft disposed at the centre of deposition chamber,
3. A substrate holder coupled to the rotary shaft for holding the substrate,
4. A heater coupled to the rotary shaft and above the substrate holder for heating the substrate,
5. A magnetron assembly for sputtering of electron ions on a deposit,
6. A pump for generating and providing a vacuum-like atmosphere
7. A shutter position above the magnetron assembly for controlling exposure of a coating material to an ion bombardment.

The magnetron assembly comprises of a first magnet stack positioned in the centre of magnetron, a second magnet stacks positioned at inner circumference of magnetron assembly for enhancing electrons during deposition, a cooling block, an insulator and a power supply means connected to the insulator for supplying power to the magnetron for magnetic field generation. Figure 1 displays schematic of the basic platform of the powder magnetron sputtering system.

2.2. Set up of physical vapor deposition apparatus

Figure 2 shows that the physical vapor deposition apparatus comprises of the deposition chamber having a heater inlet and a vacuum gauge port on top of that deposition chamber. The rotary shaft disposed within the centre and extended through the top of deposition chamber. In a preferred embodiment of the present invention, the machine is provided with two heaters including heater A and heater B, which are pivotally attached to the rotary shaft in the opposite position. An alumina rod is pivotally mounted to the rotary shaft for holding the substrate holder.

Particularly, the substrate holder is placed beneath the heater. In a preferred embodiment of the present invention, the machine includes two alumina rods positioned in such a way that a first alumina rod faces opposite to a second alumina rod.

The PPVD machine includes a panel for placing the magnetron assembly. As can be seen in Figure 2, the magnetron assembly is placed on top of the panel and beneath a rotatable shutter that pivotally mounted at the centre of the panel via a shutter bar, extended from a bottom of the panel and coupled to a drive motor. The rotatable shutter is used to control the opening and closing of the magnetron assembly for providing power to the magnetron assembly. In a preferred embodiment of the present invention, the magnetron assembly has a circular shape.

A turbo pump coupled to the deposition chamber for supplying pressurized and depressurized air to the deposition chamber. A gate valve interposed between the

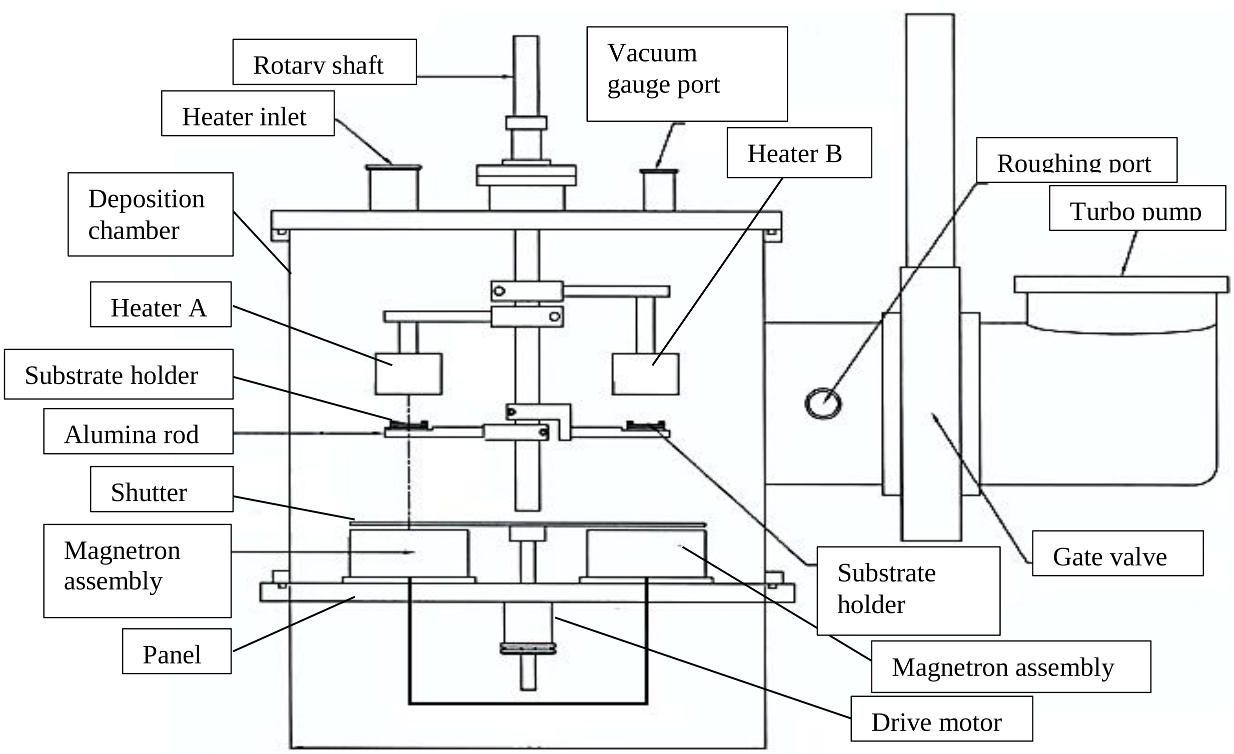

Figure 2: Physical vapor deposition apparatus

deposition chamber and the turbo pump, controls the pressure inside the deposition chamber by adjusting the flow of the air generated by the turbo pump during operation and before open a door of the deposition chamber.

2.3. Set up of magnetron assembly

Referring to Figure 3, the cross sectional view of the magnetron assembly is illustrated. The magnetron assembly comprises of the cooling block having a plurality of apertures for receiving the first magnet stack and the second magnet stack, wherein the cooling block is preferably made from chromium plated copper material. A yoke plate, preferably made from chromium plated pure ion, is coupled to the bottom of said cooling block. The yoke plate has a plurality of openings at the periphery aligning with the aperture at the periphery of the cooling block. The water cooling block coupled to bottom of yoke plate and seated on a surface of the insulator.

As can be seen from Figure 3, the water cooling block and the insulatoralso comprises a plurality of openings atthe peripheryy aligning with the aperture atthe peripheryy of the cooling block. Coupling of the cooling block, the yoke plate, the water cooling block and the insulator to each other results the engagement of the apertures and the openings at the periphery of each component, forming a channel configured to receive a fastener, such as a screw and a bolt for securing the cooling block, the yoke plate, the water cooling block and the insulator in position.

The first magnet stack is placed in the centre of the cooling block, and the second magnet stack is positioned in the periphery aperture of the cooling block. The cover that preferably made from stainless steel material such as SUS 304, is used to cover the top of the cooling block. The coating material tray is placed on top of the cover for storing the coating material, wherein the coating material is preferably a powder including metal, ceramic or a combination thereof. A first shield positioned on top of a second shield. Both of the first shield and second shield are used to confine plasma discharge inside the deposition chamber.

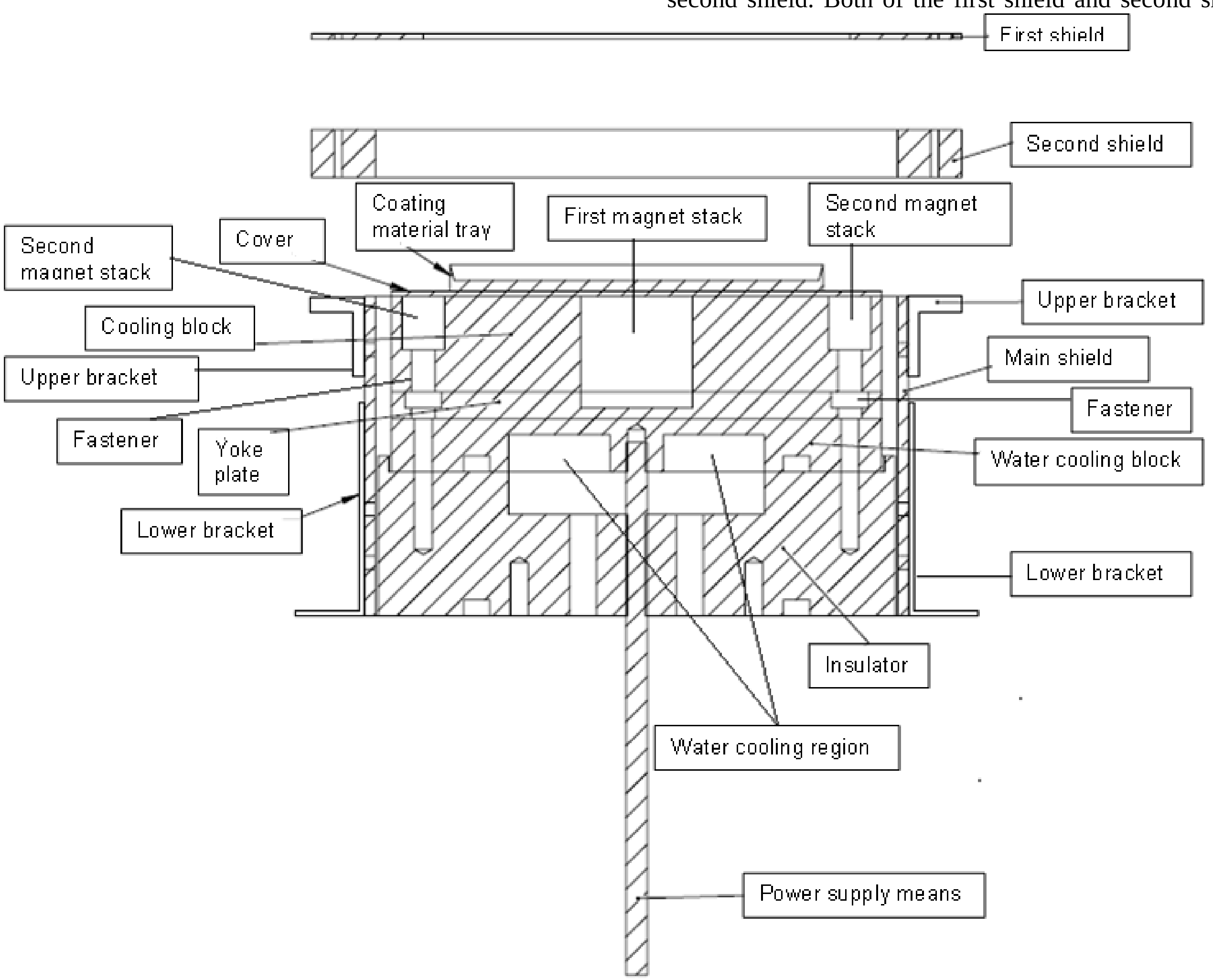

Figure 3: The cross sectional view of the magnetron assembly

The magnetron assembly further comprises an upper bracket and a lower bracket mounted to each corner of assembly to reinforce the magnetron assembly.

2.4. Design of powder magnetron sputtering

In a preferred embodiment and as shown in Figure 4 and 5, the first magnet stack comprises a minimum of two magnets, and whereas the second magnet stack consists of a minimum of four magnets. The magnet is preferably a tubular magnet. The first magnet stack has a width (X = 20 mm) similar to a height of the two magnets (Y3) in Figure 4. The second magnet stack has a width (X2 = 6mm) similar to a height of the four magnets (Y5) in figure 5. The second magnet stacks is generally has a smaller diameter compared to the diameter of the first magnet stack.

In operation, the power supply is connected to the magnetron assembly. A target subject or workpiece is placed on the substrate holder and being turned to a position under the heater A and heater B by rotating the rotary shaft. The vacuum is supplied into the deposition chamber when current is supplied from the power supply to the magnetron assembly, a magnetic field is generated. The heater is heated up. The turbo pump is actuated and begun to supply the pressurized gases including argon, oxygen and nitrogen into the deposition chamber via the gate valve.

When the magnetic field combining with an electric field generated by the magnetron assembly, this will enforce a strong electron to bombard the powder and followed by powder sputter towards a surface of the substrate and then deposited thereon. The drive motor is activated and thereby turning and positioning the rotatable shutter to open and close the magnetron assembly, exposing the coating material to ion bombardment during sputtering.

The magnetron assembly further comprises a water cooling region for regulating temperature of the magnetron assembly. Water is supplied into said water cooling region via a water input and a water output coupled to the magnetron assembly. The PPVD machine has four magnetron assemblies to enhance sputtering of ions, wherein two magnetron assemblies are equipped with the radio frequency (RF) power supply and the other two magnetron assemblies are connected to the direct current (DC) power supply.

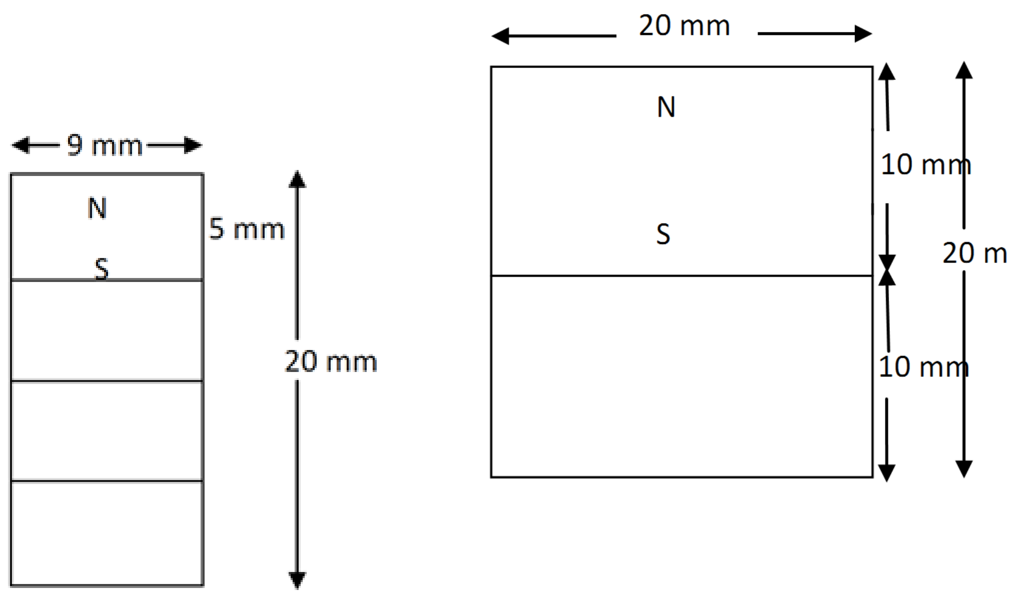

Figure 4: Cross sectional view of the magnets

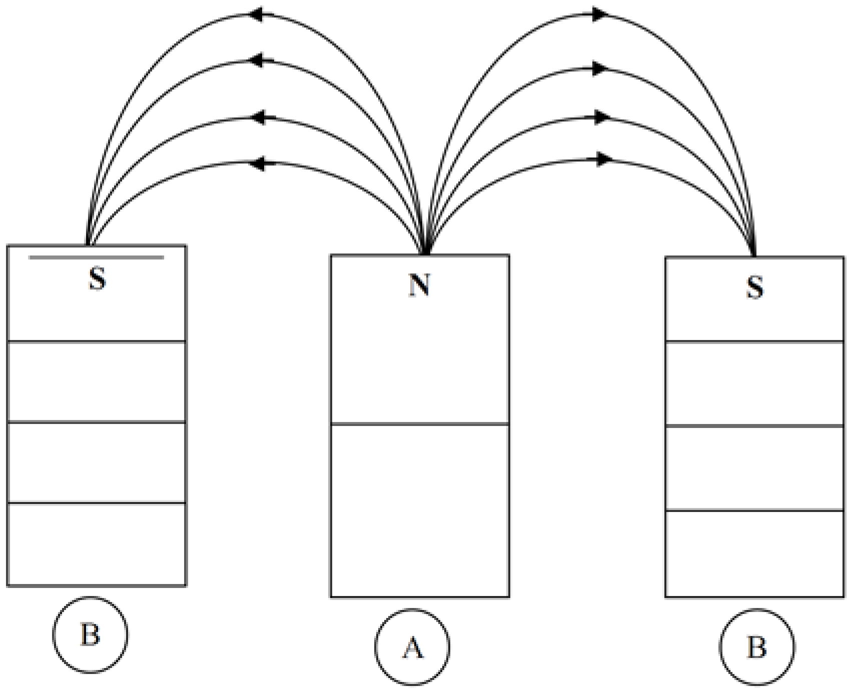

Figure 5: Magnetic field produced by the magnets

Besides that, all four of magnetron assemblies can connectoth the RF power supply only, or the DC power supply only depending on the nature of the coating material selected for one deposition time.

For example, when a metal powder is selected, the preferred power supply means will be DC power supply. DC power supply is preferably used for coating of conductive materials. For coating of non-conductive materials, RF power are preferably to be used.

The multilayer coating can be achieved using multi-layered pre-prepared coating material (powder), or using a combination of different type of coating material one after another resulting; reducing the production cost and increases the target options.

3. Summary

Multi-layered thin film coating is now more achievable using the developed powder-based target physical vapor deposition (PPVD) for a variety of advanced applications. The developed machine utilizes powder target of any inorganic solid as a source of material deposition with significantly reduced costs. The main objectives for this project were achieved as this new invention is an alternative to conventional method of physical vapor coating system by using powder. The PPVD machine provides a new technology of sputtering system for energy saving and reduction in hazardous chemical usage. In order to ensure the powder PVD instruments can be operated and function well, functionally and applicability test is required as the future works.

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