Review on Synthesis of Multilayer Nanostructures using Sputtering

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Abstract- **The process of synthesis of nanostructures and nanomaterials plays a crucial role in physical properties and associated phenomena acquired by them and hence is a deciding factor in various potential applications of the materials. The parameters like particle size, porosity, yield stress, ductility strain hardening, etc are strongly dependent on the method used for preparation of nanostructures. Thus, the know-how of skill of fabrication and processing nanomaterials and nanostructures is the first corner stone in field. This paper focus on the different existing techniques for synthesis of nanomaterials, the selection of potential process for preparation of multilayered nanostructures such that material with optimum characteristics may be obtained. This Paper summarizes the fundamentals of synthesis techniques for nanostructures and nanomaterials using sputtering. The parameters crucial for selection of technique are presented.**

Keywords—Multilayer nanostructures, sputtering, ion beam sputtering

I. INTRODUCTION

The synthesis techniques may be broadly classified as top down methods and bottom up methods. [1-4]. Sputtering is a technique commonly used for generation of multilayer nanostructures through bombardment of source material (target) with highly energized ions of potential more than 100 eV. This results in series of ejection of atoms from surface in gaseous form which are directed towards the substrate for deposition resulting in formation of thin layers. The number of atoms ejected from the surface per incident ion is called the sputter yield. The conventional DC sputtering system is shown in Figure 1.

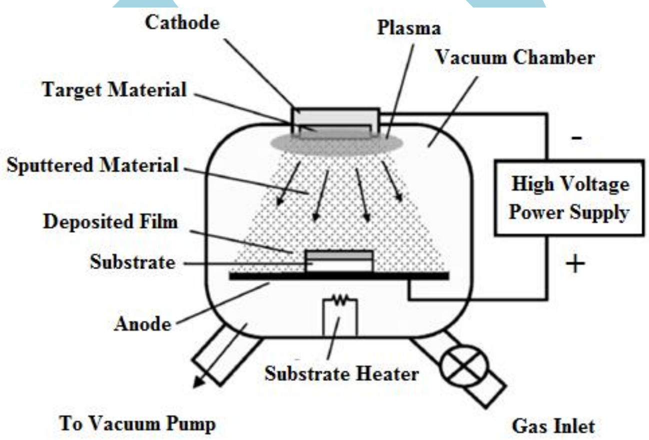

Figure 1: A conventional DC sputtering system

A substrate over which thin film deposition is to be done is placed in the vacuum chamber along with source material (target) and an inert gas (usually Argon) [6]. The high voltage power supply is given to anode-cathode arrangement and pressure of gas inlet is maintained at certain levels such that it immediately breakdown into plasma and is gathered just above the target material. The high potential ions are produced by plasma thereby creating a dark space of high potential around the cathode. These high potential ions continuously collide with cathode resulting in sputtering of atoms of target material. Some of the electrons emitted from the surface act as secondary electrons and move back to the dark regions and further strike with the gas particles. The energy of secondary electrons is sufficient enough to maintain the required volumes of plasma. The formation of plasma around the target material and cathode is shown in Figure 2. The thin film being deposited has material same as that of target but with specific crystal lattice structure.

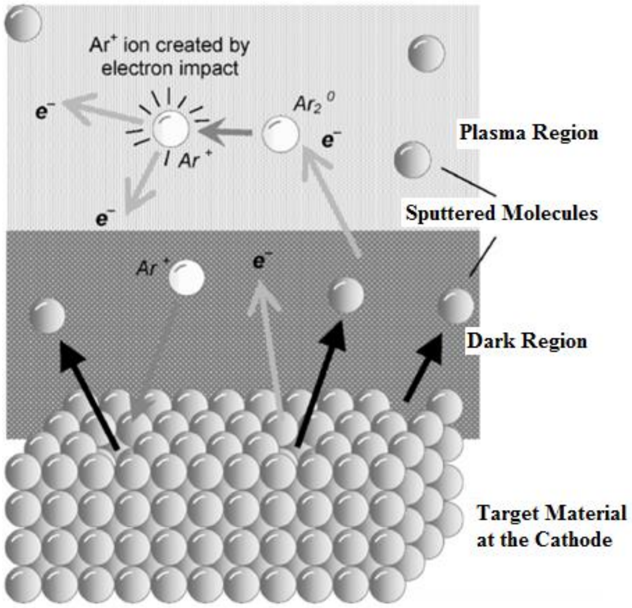

Figure 2: Formation of the dark and plasma regions above the target's surface.

II. Types of Sputtering

The several modifications that can be used for sputtering includes Ion Beam Sputtering (IBS), Ion Assisted Deposition (IAD), Reactive sputtering, High-target-utilization sputtering, High-power impulse magnetron sputtering (HIPIMS), Gas flow sputtering.

In Ion-beam sputtering (IBS), target acts as external commodity as far as ion source is concerned. The ion source generates the ions by direct collisions and doesn't require any source of magnetic field for its operation. IBS has an advantage in that the energy and flux of ions can be controlled independently. Since the flux that strikes the target is composed of neutral atoms, either insulating or conducting targets can be sputtered. IBS has found application in the manufacture of thin-film heads for disk drives. A pressure gradient between the ion source and the sample chamber is generated by placing the gas inlet at the source and shooting through a tube into the sample chamber. This saves gas and reduces contamination in UHV applications. The principal drawback of IBS is the large amount of maintenance required to keep the ion source operating [8-10].
In ion-assisted deposition (IAD), the substrate is exposed to a secondary ion beam operating at a lower power than the sputter gun. Technique finds its potential applications in carbon coating on hard disk platters, metal coating on medical implants etc.

Reactive sputtering involves chemical reaction of the sputtered particles before deposition on the substrate. Thus, the material of thin layers so formed is different from that of target material. The chemical reaction usually involves reactants like oxygen, nitrogen etc. Thus, technique is implemented for oxide or nitride thin film depositions [12, 14, 16, 18-20].

High-target-utilization sputtering involves generation of plasma in isolation to main chamber (where target and substrate are placed), thereby relieving dependency of voltage of target on ion current [22].

High-power impulse magnetron sputtering is based on magnetron sputter deposition. It utilizes extremely high power densities of the order of kW/cm2 in short pulses (impulses) of tens of microseconds at low duty cycle of < 10%.

Gas flow sputtering implements the hollow cathode effect, where inert gas is led through an opening in a metal subjected to a negative electrical potential. Enhanced plasma densities occur in the hollow cathode, which causes a high flux of ions on the surrounding surfaces and a large sputter effect.

III. Selection of sputtering technique

As there are wide variety of sputtering techniques available, one has to select the technique based on following factors:

1. Target material: Target material plays a crucial role while selecting a sputtering system. For example, thin films of insulating materials cannot be made using diode sputtering arrangement owing to its dielectric properties, while a radio frequency source may efficiently serve the purpose. It will additionally require impedance matching networks.
2. Plasma Properties: The plasma properties may be improved by using radio frequency power sources, application of modulating voltage at the target, application of magnetrons around the region etc [24].
3. Rate of deposition: The rate of deposition of thin films depends upon softness of target material, distance between the target material and substrate, voltage applied between anode and cathode etc. It may vary from several micrometers to few nanometers depending upon the user requirements.
4. Properties of films: The field where these thin films are to be used plays a vital role. The structure and surface morphology required depends not only on their own properties, but also on substrate on which they are deposited.

Among the different available techniques, IBS is widely used owing to its various advantages like:

1. The technique implements mechanical process to convert the coating material into vapours creating an opportunity to use any material for coating which is not possible by other techniques utilizing chemical or thermal processes.
2. Since the sample material is exposed to lesser thermal radiation, heat sensitive materials can be easily processed. On the contrary, other techniques like magnetron based sputtering require bombardment of high energy ions on the sample in highly magnetic environment at very high temperatures.
3. The technique has lower deposition rates, making it easy to control the physical structure of samples. It is quite beneficial for ultra thin film structures as results in reduced surface defects, high resolution device formations. The optical, mechanical and electrical properties of the material are highly influenced.

IV. IBS Apparatus

A typical apparatus used for IBS is shown in Figure 3. It consists of two ion sources, one for sputtering and second for bombardment during deposition. The major components of IBS include discharge chamber, grids and neutralizer [26].

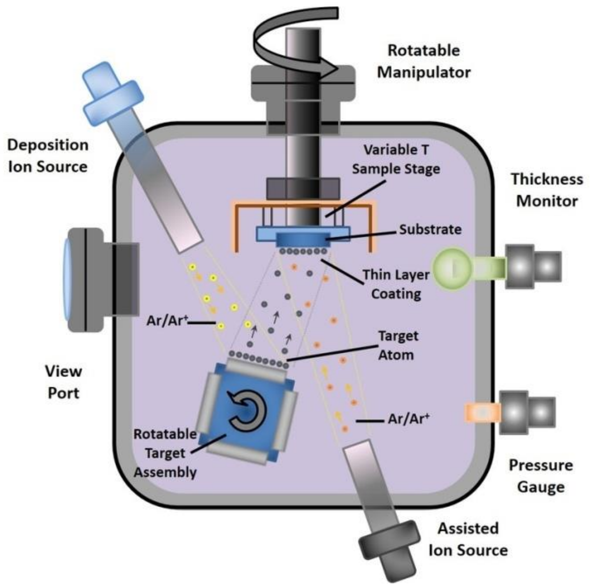

Figure3: Schematic of Ion Beam Sputter Apparatus

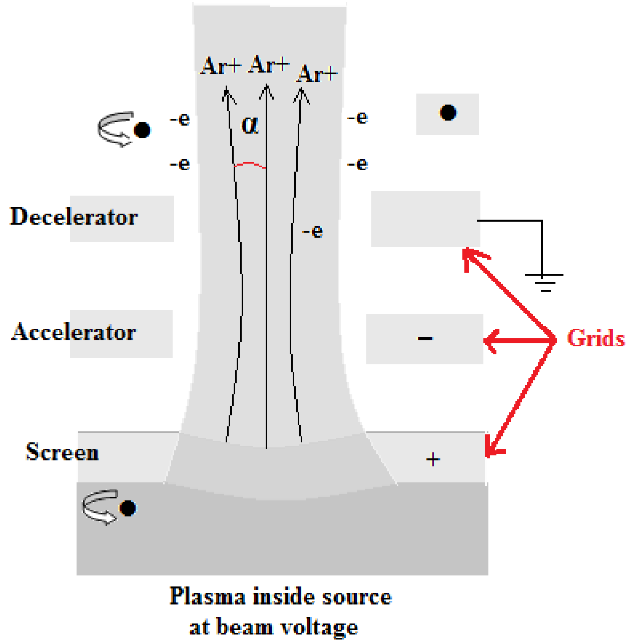

Figure4: Grid Arrangement used in IBS

V. Discharge Chamber

It is the component responsible for generation of ions. The gas like argon is injected into alumina or quartz chamber privileged with RF coil. This RF coil help in generation of ions and electrons through either inductive or capacitive coupling. The so generated ions results in establishment of plasma [28]

VI. Grids

The grid arrangement (comprising of two or three grids) as shown in Figure 4 is used either to accelerate or decelerate the ions. They normally consists of apertures with defined hole patterns and specific separating distance according to target size, sputtering rate, deposition rate required. Normally devices do have three grid system using screen grid, accelerator grid, and decelerator grid. The screen grid is in direct contact with plasma responsible for beam energy. The specific applied potential difference between the grids acts as driving force for accelerating or decelerating the ions. Since the screen grid had positive potential, other two are normally grounded to help in beam collimation, prevent back scattered electrons and minimize re-deposition of sputtered material back towards plasma or ion source [29].

VII. Neutralizer

The neutralizer is used for balancing the ion charge in the beam in order to reduce the space charge effects. It diverge the beam though repulsion of ions thereby avert the charging of the illuminated target or wafer. The extent to which a beam may be diverted depends on beam voltage, current, accelerator voltage, neutralizer current etc.

Sputter target and substrates are arranged such that typical separation between ion source and target is 30cm. The target is arranged at approximately 45o angle to ion beam. The size of target must be large enough to ensure that none of the beam passes the target without sputtering.

VIII. Aspects of IBS

The different aspects include the quantifying parameters that determine the uniformity and rate of film depositions. Among the different parameters used to represent the performance of IBS technique, the terms of prime concern is sputtering yield and its relation with ion energy, angle of incidence of ions, energy levels associated with sputtered particles, angular distribution of sputtered atoms etc.

Sputtering yield: It in defined as average number of extracted atoms per incident particle and is given by mathematical expression

$$Y(E, \alpha_{ST}) \approx \frac{4.2\, F_D(E, \alpha_{ST})}{N U_o}$$

Here, N and Uo are target density and average surface binding energy of the target element.

F_D (E, α_{ST}) is the depth distribution of deposited energy. [101]. It is dependent on ratio of mass of target to that of incident mass, ion energy (E), incidence angle of ions (αST) with respect to target normal.

Y has threshold value of approximately 10-30eV for most ion-target combinations and reaches a maximum value for ion energies E ≤ 20keV. Also, Y reaches maximum value for incidence angle α_{ST} varying from 60o to 800. The reflection of ions increase if the angle of incidence is increased further, thereby decreasing Y.

The energy distribution of sputtered particles is strongly dependent on ion energy E, ion incidence angle α_{ST}, emission angle ζ. With increased E, it increases maximum upto a point where energy equivalent to half of surface binding energy is attained and thereafter decrease as 1/E2. It decrease rapidly with increased ζ and is lowest for atoms sputtered towards normal to target. The sputtered species retains the emission energy between 0.1 to 100 eV, while energy distribution between 5-20 eV. Also, the energy has almost negligible dependence on crystal structure of target material.

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