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Characterization of Thin Film Nickel (Ni) Deposition by Sputtering Method

Slamet Widodo, ***Member, IEEE***
Indonesian Institute of Sciences
Research Center for Electronic & Telecommunications (PPET-LIPI)
Jl. Cisitu No.21/154D, Komplex LIPI Sangkuriang,
Phone: +62-22-2504660, Fax: +62-22-2504659, Bandung-40135, Indonesia
E-mail: slametwidodo50@gmail.com

Abstract

In this paper described the results of the testing and measuring the thickness of thin film deposition for targets nickel (Ni) using the RF-Sputtering indicated the existence of a strong relationship between the film thickness with a deposition with sputtering systems that are linear. Also shown in the characteristic curve pressure conditions argon (Ar) is constant, an increase in rated power ranging from 100 to 300 watts cause deposition speed while the value added to the value of 300 to 450 watts, the value increased deposition speed approximately constant. And on the condition of constant power, increasing gas pressure argon (Ar) decreases the value deposition speed.

Keywords: *Deposition, Thin Film, Nickel (Ni), RF-Sputtering.*

1. Introduction

The rapid development in the field of microelectronics, especially in Indonesia to encourage the emergence of a desire to produce components themselves are much needed in the electronics industry. With the development of hybrid circuit technology that existed at the moment, is one of the areas of microelectronics that can already be designed and made to be applied directly. Examples of the use of hybrid technology ie Thin Film Technology which is widely used in electronics applications such as microstrip microwave systems Satellite Communications and Earth Station.

To produce a thin film circuit or component, must go through several stages of processing which is done systematically and repeatedly. Each process has procedures and techniques of making respectively. One of the processes that must be performed on the manufacture of components or a series of thin film that is coating material (deposition) on a substrate using a sputtering system [1-3].

Sputtering system may be superimposing different types of metals and metal guide (metal alloy) or non-metal on the substrate so that the hybrid circuit industry, sputtering system is widely used as one of the major steps to make the thin film layer on the substrate.

The ongoing process in the thin film deposition sputtering system is indicated by the invisibility of glow discharge plasma or visually. The emergence of plasma or glow discharge depends on the setting value of the gas pressure and power (current and voltage) provided in the sputtering system. Results of the sputtering deposition process such as the thickness of the film formed on the substrate. Each type of coating material used, the thickness of the resulting film is different for the same deposition time. Because each type of coating material influenced the nature and the mass of the constituent particles. How far the influence of the gas pressure and the power of the film thickness are formed for a particular deposition with sputtering systems, can only be known through research in the sputtering process to various types of coating materials.

In thin-film technology, there are two ways that can be used to create a thin layer on a substrate by vapor deposition (Physical Vapor Deposition), namely:

- Evaporation Vacuum, the deposition of the coating material in the form of steam due to the heating of a metal in a low vacuum pressurized space.
- System of sputtering, deposition coating material in the form of material thrown from the surface of a metal as a result of being shot by high-energy particles in a low-pressure vacuum chamber.

Sputtering system is a system that most benefits compared with vacuum evaporation[4].

- Can be superimposed films of metals, alloys, insulators, semiconductors and even magnetic metals.
- Speed of deposition for each type of material is not much different.

• Can do a lot of layer deposition (multilayer) well as ability to coat various types of metals.
• The film thickness is easier and simpler to be observed and controlled.
• Power adhesion between the film and the substrate surface is stronger.

2. Methodology

The process of deposition of metal and non metal (Alloy) conducted by Sputtering method. The tools used are Sputtering Machine (Plasma Science ARC-12 M). This tool can be operated by DC Sputtering (for material deposition process that is both conductor) and RF Sputtering (for conductor and non conductor). In this study conducted a metal deposition nickel (Ni) with variable time (minutes), power (watts), and the pressure of the carrier gas of argon (Ar) (mTorr).

Sputtering system may be superimposing different types of metals and metal guide (metal alloy) or non-metal on the substrate so that the hybrid circuit industry, sputtering system is widely used as one of the major steps to make the thin film layer on the substrate [5-6].

Sputtering is a process deprived (ejected) material from a surface of a solid or liquid substance due pounded by high-energy particles to an exchange of momentum (momentum exchange). Target form coating material is placed in the direction of the substrate (Figure 1) in a vacuum chamber with the initial pressure (base pressure) of $5x10^{-4}$ to $5x10^{-7}$ Torr. Type of particles originating from the ion gas fired inert substances or other inert gas. The material thrown off in the form of atoms of a metal or metal mixture will stick to the surface of the substrate [7].

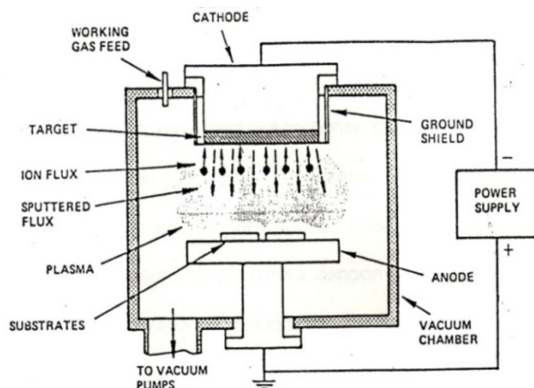

Figure 1. Planar Diode Sputtering System with Glow Discharge [7]

The method most commonly used to produce ions pounder is inserting argon gas (Ar) into a vacuum chamber with a pressure of between 1 to 100 mTorr when given a direct voltage between the two electrodes until an electrostatic discharge (electric discharge) on the target. This is the process of ionization of the gas at the same time clearly be seen a Plasma or glow discharge. Argon gas ionization due to the voltage difference between the two electrodes that have a certain distance so as to produce electrons jump very quickly from the cathode to the anode.

2.1 Basic Principles Sputtering

When ions are fired at high energy to a solid surface, there will be many phenomena. Shooter particle kinetic energy is crucial events that arise. In the energy slightly exceeds the binding energy of the atoms (sublimation energy target) physically will only damage the surface of the target. For very high energy which is about 4 times the sublimation energy targets, then the particles will be embedded in the target, and this phenomenon is the basis of ion implantation [4].

Two important events which are the basic principles sputtering. The first is deprived of atoms from the target surface due to the transfer of energy by ions of high energy comminution/pulverization. The exchange of momentum between the ion collider with the atoms of the sputtering target of an event that can explain the process deprived atoms. Secondly, the tube will look for a sheen of light (glow discharge) which is the continuous plasma. It denotes process of deposition / coating is underway within the tube.

2.2 Sputtering System with Radio Frequency (RF)

On target species isolator can not coat the substrate using direct current sputtering system DC-sputtering because the voltages used will prevent the occurrence of neutralizing the positive charge gathered on the surface of the target, while pounded by ions. Accumulation of positive charge would cause a potential difference between the cathode and the anode becomes smaller.

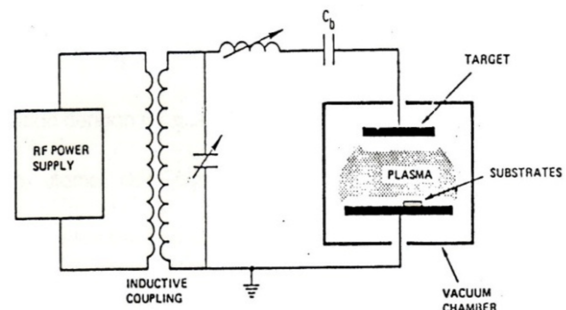

Figure 2. RF-Sputtering System with Planar Diode Impedance Matching Circuit [7]

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As a result, the state of glow discharge can not be maintained even be deadly glow discharge. To overcome that is by using an alternating voltage with high frequency. Due to the frequency on the use of radio frequencies then this process is called RF sputtering. Devices using RF sputtering system shown in Figure 2. The radio frequency that is often used in industries, fields of scientific research and the field is 13.56 MHz [8].

RF-sputtering has many advantages compared to DC-sputtering because in addition to insulating material, the system can also use the target type of conductor, resistor, and dielectric. With the advantages of RF-conductors, resistors and dielectrics. With the advantages of RF-sputtering add functionality and usability of the sputtering system itself so that the system is widely used in industries of electronics, especially in the field of thin film technology.

2.3 Sputtering System ARC-12M

ARC-12M sputtering system works automatically with microprocessor-based electronic control circuit connected directly (interface) with a PC via a serial port. The convenience provided by the manufacturer of the device is that when the operator wants to operate each stage of the process is only through a PC computer keyboard. Each stage of the process is automatically sputtering system has been arranged in sequence so that if at one stage there was an error or not achieved the minimum conditions for the next stage will not be executed.

In the block diagram, ARC-12M sputtering system there are three parts of the first main.The part of a core device consisting of a turbo molecular pump, three planar magnetron source (gun), three DC-power supply, a cylindrical tube made of steel (Vacuum Chamber), microprocessor-based electronic control circuit connected directly 80C51 to PC computer. The second part is a device accessories comprising a radio frequency generator (RF-generator) and a tuner. While the third part is a computer controller and a monitor for the operator which consists of a set of PC computer together with the software. As for the non-conductor material (insulator, dielectric) deposition process must be carried out by RF Sputtering, because the potential acceleration of the DC source can not be used directly on the surface of the insulator.

Here, the gas ions which reach the surface of the target can not be neutralized because of the unavailability of free electrons. Ions to form positively charged layer on the surface of the target which resulted in cessation of the sputtering process in the absence of Glow Discharge. This problem can be overcome by using alternating voltage at a radio frequency of 13.56 MHz. By RF Sputtering, deposition process can be done using the targets that are insulators, conductors, resistors and dielectrics.

Sputtering apparatus used herein is equipped with a monitor measuring the thickness (Thickness monitor). The working principle of this thickness gauges is the vibration frequency of the crystal oscillator will change according to the thickness of the resulting films. The more particles attached deposition process results in crystals, crystal oscillator vibrations would be lower. This frequency difference is converted as the difference in thickness, which immediately appear on the monitor screen. The ARC-12M Sputtering tool can be seen in Figure 3 below.

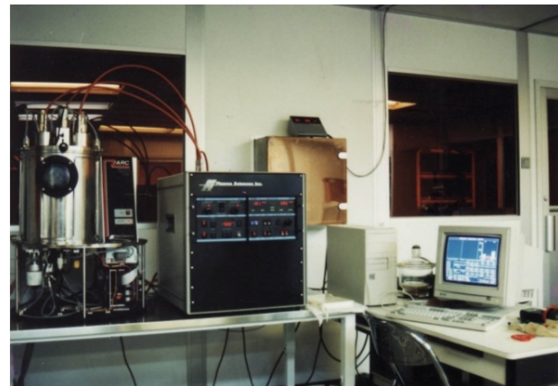

Figure 3. Equipment ARC-12M Sputtering System

2.4 In the deposition speed Sputtering

In a sputtering system, deposition speed is affected by the results of Sputtering (Sputtering yield), Sputtering Speed (Sputtering rate) and pollutant (Impurity trapping).
Value Results Sputtering (Sputtering Yield)
Sputtering yield value is the number of atoms that bounce off the target by one ion pounder. To analyze the changes that occur in the sputtering process, has been known for the analysis of Sigmund's linear Cascade makes the correlation between ion energy (eV) with Sputtering Yield (atom / ion).

Sputtering analysis of the results is determined by the following equation:

$$S = K \frac{M_i M_t}{(M_i + M_t)} [E/U] \alpha \qquad (1)$$

with:

α = function of Mt / M,
S = the value of the sputtering (atoms per ion)
E = the energy of ion collider (eV)
U = sublimation energy (eV / molecule) α
K = constant of 0.1 to 0.3.

Energy threshold (Threshold energy)
Energy threshold (Threshold energy) is a minimum-owned energy ion collider so that ions of the target bounced, so the sputtering process can occur. In the sputtering process, the relationship between the sputtering threshold energy is as follows:

$$S = \alpha\left(E^{1/2} - E_{th}^{1/2}\right) \quad (2)$$

$$\alpha = \frac{k}{U}\frac{Z_t}{\left[Z_t^{2/3} + Z_x^{2/3}\right]}\left\langle\frac{Z_x}{Z_t + Z_x}\right\rangle^{0.67} \quad (3)$$

with:
E = the energy of ions (keV)
k = constant (5.2)
Eth = threshold energy (KeV)
U = sublimation energy (eV per particle)
Z_1 = atomic number of the target
Zx = number of gas atoms (ions pounder)

If a gas molecule composed of m number of atoms, the equation becomes:

$$S = m^{1/2} - \left[(mE_{th})^{1/2}\right] \quad (4)$$

2.5 Sputtering Speed (Rate of sputtering)

Sputtering speed is defined as the number of atoms per unit time and broad bounce. At the time of ion current density or flux current (Ji) equals the ion flux q multiplied by the electron charge, the speed sputtering is

$$r_s = \frac{Sj_i}{q} \quad (5)$$

with:
rs = speed sputtering
Ji = Density of ion current (A cm^{-2})

Impurity trapping
Gas argon (Ar) is used as an ion collider, can contain impurities in the deposition process involved deposited on the substrate. Oxygen go in together with argon gas (Ar) can also react with the atoms on the target so as to affect the resistance and adhesivitasnya film coating on a substrate.

Stages of the process are as follows:

a. Cleaning the substrate
This stage is very important, because it determines the quality of the thin film layer is formed. Impurities contained in the substrate materials are issolved with a chemical solvent. In order to perfect the cleaning process, the cleaning process is done in Ultrasonic cleaner. The chemicals that are commonly used among others are Trichloro Ethylene (TCE), Trichloro ethan (TCA), ethanol, or acetone.

b. Sputtering Stage

Sputtering process is performed on the operating mode RF Sputtering, with initial pressure (base pressure) ranges between 10^{-5}-10^{-6} Torr. Having achieved these conditions included gas argon (Ar), until it reaches a constant pressure of about 4 mTorr. The supplied power is 100 watts. Conductor material deposition can be performed by RF-Sputtering [9-10].

Before the deposition process, first carried out the etching process of the substrate to be coated. The trick is to reverse the direction of ion collider to the substrate with a low energy, so it just enough to clear the particles of impurities without damaging the surface of the substrate. This method can increase the power of the adhesive film on the substrate surface. The deposition process is performed using the desired target [11-12].

In the sputtering apparatus used herein, can be installed three kinds of targets, which are used interchangeably. Sputtering apparatus used herein is equipped with a monitor measuring the thickness (thickness monitor). The working principle of this thickness gauges is the vibration frequency of the crystal oscillator will change according to the thickness of the resulting films. The more particles attached deposition process results in crystals, crystal oscillator vibrations would be lower. This frequency difference is converted as the difference in thickness, which immediately appear on the monitor screen.

3. Results and Discussion

3.1 The film thickness of nickel (Ni) versus time
With the pressure of argon gas (Ar) 15 mTorr and 300 watt measurement data obtained by the measurement time data deposition for film thickness Ni

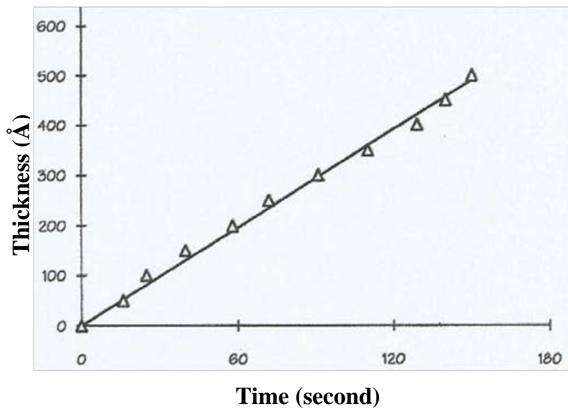

Figure 4. The film thickness curve relationship nickel (Ni) versus Time

Table 1. Conditions deposition process nickel (Ni)

Base pressure	2 - 5 x 10^{-5} Torr
Power	300 Watt
Gas pressure	15 mTorr
Rotation	10 Rpm
Gun / Shutter	2/2

3.2 Characteristics deposition speed nickel (Ni)

From the results of measurements and tests during deposition performed against targets 80Ni-20Cr, deposition speed for each gas pressure argon (Ar) and a given power. Speed characteristic curve deposition nickel (Ni) is shown in Figure 5.

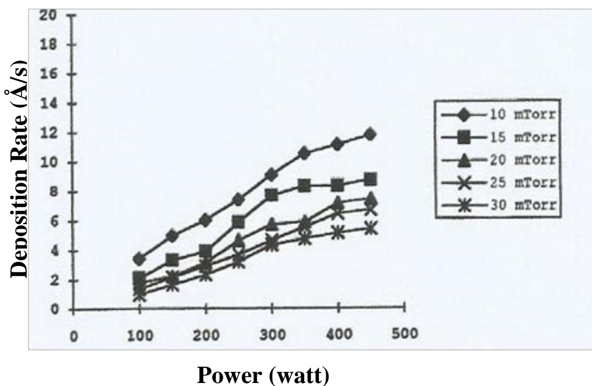

Figure 5. Characteristic curve deposition speed for nickel (Ni).

From Figure 5 it can be seen that the deposition rate increases with increasing power, especially at 100-300 watts, but to increase the power of 300-450 watts, speed of deposition showed nearly constant value.

Results sputtering will rise slowly with increasing energy, on the other hand, mashing cathode material which is proportional to the current density. The addition of power will result in an increase in current density and an increase in voltage, because the power is current with voltage multiplication. Increasing the voltage will increase the energy possessed by the ion-ion collider so that the number of target atoms that bounce off of the surface is growing. It is empirically Sputtering results will improve.

An increase in current density will increase the charge on the surface of the target so that it will accelerate the ions towards the target pounder. In addition, the current betambahnya will increase the number of electrons emitted from the target, thus increasing the number of collisions ionization.
Increasing the number of ionizing collisions will increase the current density of its ions, thus empirically increase the speed. sputtering. Constant speed deposition with increasing power of 300-450 watts due to the number of atoms that bounce off the surface area is limited also by the target.

4. Conclusions

1. In the deposition process nickel (Ni) with the RF-sputtering method, the thickness will increase linearly with increasing time.
2. From nickel (Ni) are deposited, in argon gas pressure of 15 mTorr produce Ni deposition is relatively higher than the pressure of 25 mTorr.
3. The higher the argon gas pressure, the slower the deposition speed, even at pressures above 130 mTorr argon (Ar) gas deposition process will run very slowly, because most of the material that settles back on the cathode because of the diffusion process.
4. The deposition speed increases with increasing power, especially at 100-300 watts, but to increase the power of 300-450 watts, the increase in the speed of deposition showed nearly constant value.
5. Figure 4 and 5 show the target Ni and an example of the deposition by means of RF Sputtering.

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