Study of Electrical Properties of Nano Capacitor Fabricated by Thermal Evaporation Method for application in Storage Devices

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Abstract: ***The present paper work is about fabrication of nano-capacitor by thermal evaporation method and study of its capacitance variations. The metal – insulator – metal typenano-capacitor is prepared on corning7059 glass substrate as layer by layer grown by thermal evaporation method. Capacitance of the nano-capacitor is studied with varying frequency and thickness of the dielectric (SnO_2) with precision LCZ meter) and digital multimeter from the observations it was noted that capacitance is increasing with decreasing the thickness of the insulator and at lower frequencies capacitance is more. The classically calculated results are compared with experimental work; it was noticed that capacitance increased drastically for thenano layer dielectric capacitors from nanofarads to millifarads. For the dielectric thickness of 800 nm nano-capacitor can store more energy than other 1000 nm and 500 nm thickness of dielectric nano-capacitors. Operating frequency of these nano-capacitors is from 40 Hz to 200 KHz. In this frequency range they exhibit capacitance in the order of millifarads, after that falls to micro farads range.***

Keywords: Nano-capacitor, capacitance, thermal evaporation, MIM

1. Introduction

Next generation advances in nano-electronics required circuit elements at the nanoscale. Capacitors are the crucial elements in modern electronics. Capacito**r**, sometimes referred to as a Condenser, is a simple passive device that is used to “store electricity”. The capacitor is a component which has the ability or “capacity” to store energy in the form of an electrical charge producing a potential difference like a small rechargeable battery. There are many different kinds of capacitors available from very small capacitor beads used in resonance circuits to large power factor correction capacitors, but they all do the same thing, they store charge.
Fast growing nanotechnology offering the energy demands of portable and wearable electronics [1]. Energy storage devices such as capacitors have drawn much attention for potential applications in various electronic products [2].To shrink the size of capacitors with improving efficiency, one approach to making such devices is by thermal evaporation method [3].To increase capacitance different options are available, among them changing the dielectric thickness into nano scale is a good approach.

2. Experimental Details

GenerallyCapacitor consists of two parallel conductive plates which are prevented from touching each other by an insulating material called the “dielectric”. Our experiment reveals the two parallel plates are nano-film of Aluminum and the dielectric as a nano layer of tin oxide film. A nano-capacitor with a dielectric layer (Metal – insulator – metal) type was fabricated on glass substrate (corning 7059) by thermal evaporation method. Electrical properties such as capacitance, impedance, etc., with respect to frequency are studied. For this work we have chosen aluminum (99% purity) as metal electrode material and tin oxide (SnO_2) as dielectric substance.By using precision LCZ meter (Model: Techred 1062) and digital multimeter (Model: Kiethly 2000) capacitance variations with respect to frequency changes from 40 Hz to 200 KHz are observed. On a cleaned glass (corning 7059) substrate we first deposited the aluminum electrode layer, next tin oxide insulator layer and then finally other aluminum electrode coating is given. For this deposition process we used thermal evaporation unit (Model no: 12A4D).

2.1 Cleaning

Glass substrates which are used for fabrication of nano-capacitor are thoroughly cleaned with cleaning liquid soap to remove dirt and oil or grease, then with acetone to remove organic particles. Finally cleaned with distil water and dried.

2.2 Deposition of layers

On the cleaned glass substrate a thin layer of aluminum (of thickness 500 nm) is deposited as one electrode, over this metal electrode layer tin oxide (SnO_2) layer of 500 nm is deposited up to ¾ of the substrate area as shown in the schematic diagram fig-1 and 2. Over this tin oxide coating finally a thin layer of aluminum 9of thickness 500 nm)is deposited as second electrode covering only a small area (3cm x 1.2cm). Similarly other nano-capacitors with dielectric thickness 800nm, 1000nm and areas of 2cm x 1.4cm and 3cm x 1.5cm are also fabricated.To get uniform thickness and homogeneous layers in thermal evaporation unit deposition chamber substrates were kept 10 cm above the source and pressure inside the chamber maintained at $2\times10^{-5} m.bar$ lowest pressure. At this pressure there will be no chances of collision of depositing atoms/ions with other molecules, it enhances the linear motion of the depositing matter which gives better uniformity of the film.
The rate of deposition was maintained at 6-8 ^{0}A per sec throughout the experiment.

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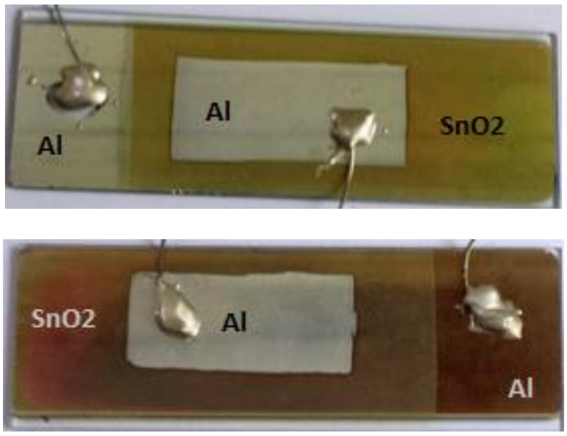

Figure 1- Fabricated nano-capacitors

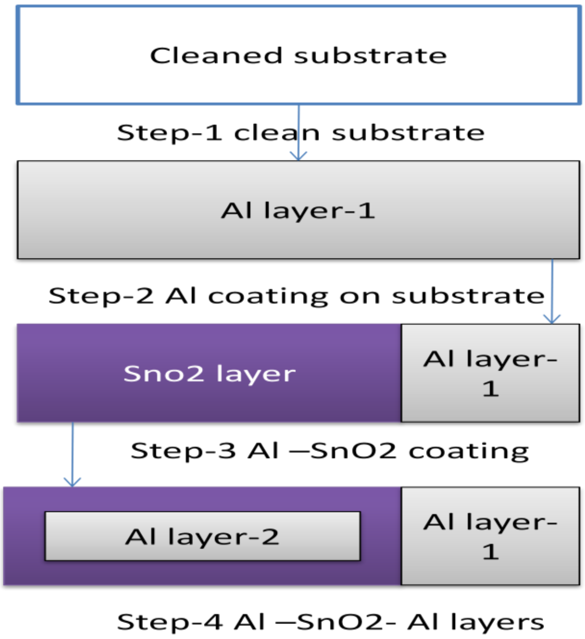

Figure 2: Schematic diagram of nano-capacitor fabrication

3. Characterization

The most important characteristic of a capacitor is its capacitance. The capacitance C describes the property of a capacitor's capability to store electrical energy if a given voltage is applied. Capacitance denotes how many units of charge can be stored in the capacitor per voltage unit. Furthermore, the capacitance is important for the AC resistance of a capacitor at certain frequencies, essentially the properties when used in filters.

Electrical properties such as capacitance, impedance are studied with the help of LCZ meter (Model no: Tech Red 1062) and digital multi meter (Model: Keithley 2000). Capacitance variations with respect to frequency changes from 40 Hz to 200 KHz are observed and plotted. Impedance also noted down from the observation and tabulated the results as following. To do this work aluminum electrodes are joined with two copper wires with the help of silver paste which enables nano-capacitor electrode terminals easily connect to the LCZ meter or other electronic device without any damage to the nano layers.

3.1 Capacitance

One of the most important one among all capacitor characteristics is the nominal capacitance (C) of a capacitor.This nominal capacitance value is generally measured in pico-farads (pF), nano-farads (nF) or micro-farads (uF). But here in nano-capacitor we found capacitance in milli-farad (mF). This nominal capacitance value may change with working temperatures and with the circuit frequency.The capacitance value of a capacitor varies with the changes in temperature which is surrounded the capacitor. Because the changes in temperature,causes to change in the properties of the dielectric. Working Temperature is the temperature of a capacitor which operates with nominal voltage ratings.

Theoretically capacitance of parallel plate capacitor with dielectric presence is given by the equation

$$\text{Capacitance } C = k\varepsilon_0 \frac{A}{d} \quad \text{.......... (1)}$$

Where ε_0 is the absolute permittivity, **k** is dielectric constant of tin oxide at room temperature (9.86). **A** is area of the dielectric film and **d** is the thickness of the dielectric (distance between the conductor electrodes). Capacitance of the three prepared capacitors are calculated and tabulated.

Table 1: Theoretical & Experimental Capacitance Values

Capacitor no.	*Thickness of SnO_2 (dielectric) layer d (nm)*	*Area of the capacitor A (cm^2)*	*Theoretical capacitance value **(nano farad)***	*Experimental capacitance max value **(mille farad)***	*Experimental capacitance at 50 Hz **(mille farad)***	*Capacity density (mF/**cm^2**)*
01	1000	2.8	24.44	50.93	24.59	18.19
02	800	4.5	49.10	129.35	60.73	28.74
03	500	3.6	62.85	77.67	8.772	21.57

From the above data it is clear that capacitance increased drastically from nanofarad range to millifarads.Increasing thickness decreases the capacitance. At low frequencies the capacitance values are high because dielectric constant of the insulator is more at low frequencies. The dielectric constant has higher values at the lowerfrequency and then it decreases to the high frequency may due to the contribution of the electronic, ionic, dipolar and space charge polarizations, which depend on the frequencies [4]. At frequency of 200 Hz the capacitance values are shown more.

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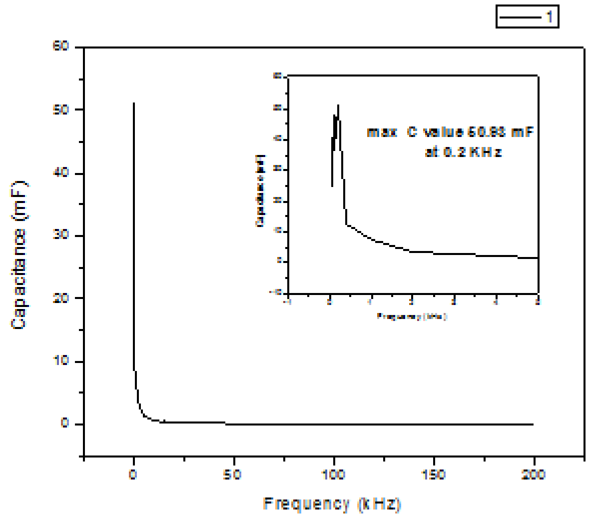

Figure 3: Capacitance vs Frequency of nano-capacitor-01

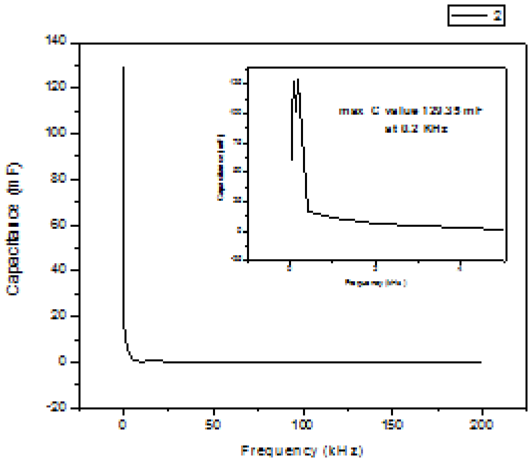

Figure 4: Capacitance vs Frequency of nano-capacitor-02

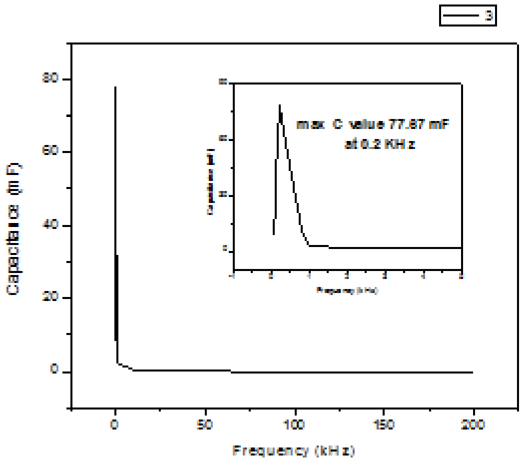

Figure 5: Capacitance vs Frequency of nano-capacitor-03

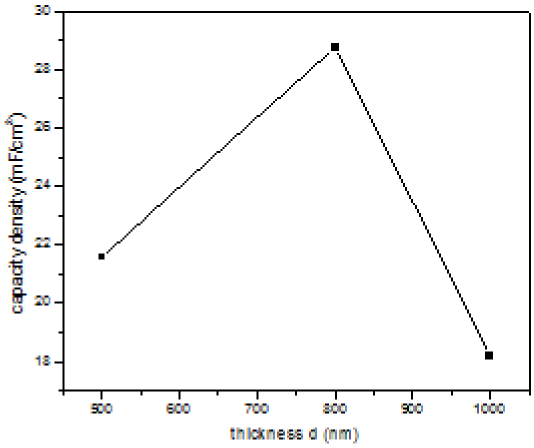

Figure 6: Capacity density vs thickness of dielectric

From the graphs it can be observed that capacitance is more at low frequencies, after 5 KHz frequency capacitance values are decreased andat frequency of 200 Hz the capacitance values are 50.93 mF, 129.35 mF and 77.67 mF which are the maximum capacitance values achieved by the nano-capacitors. At general frequency 50Hz the capacitance is as 20.59 mF, 60.73 mF and 8.77 mF respectively. It is also depicted that the optimum thickness of the dielectric thickness is 800 nm and operating frequency range for these capacitors is 40 Hz to 5 kHz, after words the capacitance values are decreased from mille farad to micro farad (less than 1 mF). For the thickness of dielectric at 800 nm it can store more energy compared to other thicknesses.

3.2 Capacitive reactance

The AC impedance of a capacitor is known as capacitive reactance X_c. It depends upon frequency and it decreases with increasing frequency. Capacitive reactance is given by theoretically as follows,

$$X_c = \frac{1}{2\pi f C} \qquad \text{------- (2)}$$

Where X_c is Capacitive reactance in ohms, f is frequency in Hz and C is the Capacitance of the capacitor.When the applied frequency increases, it reduces the capacitive reactance similarly decreasing frequency can also increase the capacitive reactance. This is known as complex impedance. Which is an imaginary value ($z = \frac{1}{i\omega C}$) because of electrons on the capacitor plate can go to other plate with varying frequency. The graph between the capacitive reactance and frequency depicts that increasing frequency decreasing the X_c value within the range of 1 KHz later it gradually increased. At low frequency we have high capacitive reactance and it is again increased which is odd from classical behavior. At nano scale dielectric properties are differ from classical one.

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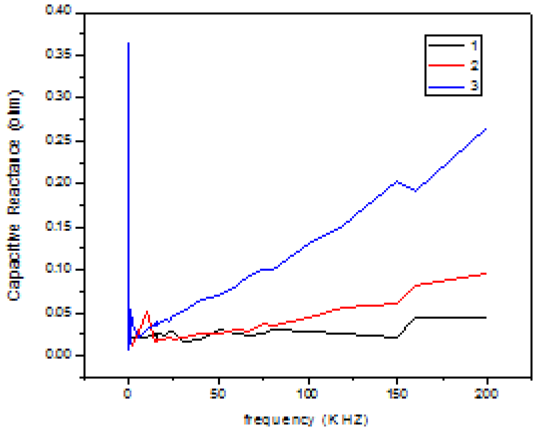

Figure 7: Capacitive reactance vs Frequency

3.3 Equivalent Series Resistance

The equivalent series resistance (ESR) of a capacitor is defined as the AC impedance of a capacitor when it usedat very high frequencies and also with the consideration of dielectric resistance. Both the DC resistance of dielectric and the capacitor plate's resistance are measured at a particular temperatures and frequency.ESR acts like a resistor in series with a capacitor. The ESR of a capacitor is the rating of its quality. We know that theoretically a perfect capacitor is lossless and also have the ESR value zero. Often this resistance (ESR)causes to failures in the capacitor circuits. In our experiment ESR values of the nano-capacitors are 108.3ohm, 12.77 ohm and 185.36 ohm for tin oxide thickness 1000nm, 800nm and 500nm respectively.

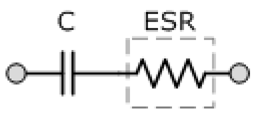

Figure 8: ESR Model

As ESR defines the energy losses of the "equivalent" series resistance of a capacitor it must therefore determine the capacitor's overall I^2R heating losses especially when used in power and switching circuits. Hence the nano-capacitor with less thicknessof tin oxide produces larger heating losses. Capacitors with a relatively high ESR have less ability to pass current to and from its plates to the external circuit because of their longer charging and discharging RC time constant. Capacitors with very low ESR ratings are best suited when using the capacitor as a filter.

4. Conclusion

Metal – insulator – metal (Al– SnO_2 –Al) type nano-capacitors are fabricated by thermal evaporation method. Capacitance variation of these nano capacitors are studied with respect to frequency range from 40 Hz to 200 KHz. Theoretical capacitance values are compared to experimental values, theoretical calculations suggested very low capacitance (in nanofarad range) but experimentally these nano layer dielectric capacitors shown very large capacitance (in millifarads). Because of changes in thickness of insulator (SnO2) and its dielectric constant value varies with applied frequency. From the experimental observations it was noticed that at optimum frequency range from 40 Hz to 5 KHz capacitance values are more after 5 KHz capacitance decreased to micro farads. For optimum thickness of dielectric 800 nm it has more capacity density when compared to other thicknesses. It has also less ESR therefore more suitable for filter circuits.From this experiment we may conclude that nano-capacitors make excellent energy storage devices because of their high values of capacitance. The nano-capacitor have capacitance much more than other capacitors with same thickness of dielectric and its large capacitance within a very small physical size and hence can achieve much higher power density than batteries. Therefore nano-capacitors can be used as energy storage devices similar to a battery.

5. Acknowledgement

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