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Al and Cu Thin Film Capacitors for Void Fraction Measurement

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ABSTRACT

The fabrication of thin film based capacitors with different metal electrodes (Al, Cu) and their application towards void fraction measurement is carried out in this study. Void fraction is a measure of empty spaces in any medium. The void fraction is measured as capacitance in the capillary tube and processed through embedded system. The thin film capacitor is designed on a capillary tube through thermal evaporation technique with the above given metal elements. Capillary tube with different diameters ranging from 5-10 mm and length of 7 inch were used and deposited with metal elements mentioned above with a small distance between them. The capillary tube is used as insulator with metal elements deposited above them as metal electrodes. Changes in capacitance value due to the voids were measured through LCR/Z meter. Before coating the electrodes on the capillary tubes, the films were characterized for their structural, morphological and electrical properties to obtain capacitors with desired value of capacitance.

Key words: Thin films, capacitance, thermal evaporation, void fraction

INTRODUCTION

Void fraction is a measure of the void (empty) spaces in a material and is a fraction of the volume of voids over the total volume. The proposed void fraction measurement device is designed by using thin film deposition technique that is a non invasive type measurement technique, which measures void fraction in terms of proportional capacitance and can be used for volume measurement, void sensing etc., in automobiles and flow sensing in medical applications. There are different methods involving optical, electrical type sensors etc. (Demori *et al.*, 2010; Jaworek *et al.*, 2004; Pranav *et al.*, 2013; Zhu *et al.*, 1991; Uesawa *et al.*, 2012) are used for void fraction measurement but in this study capacitive type is chosen which is not invasive (Zhu *et al.*, 1991) or do not destruct the flow. Uesawa *et al.* (2012) proposed intrusive method of measuring void fraction.

When the electrodes are subjected to potential difference an electric field is said to be generated which exhibits capacitance. The capacitance will be directly proportional to product of dielectric constant of the insulating material and area of electrode and inversely proportional to distance between the electrodes. Al and Cu metal elements are cheap and good conductor of electricity and hence they are used to form metal electrodes on glass substrates to develop thin film capacitor. The material is thermally evaporated on the substrate and is used as metal plates, electrical contacts will be taken from these electrodes for capacitance measurement. In order to have simple design and effective measurement, capillary tubes are used as insulating medium, that is thin film deposition

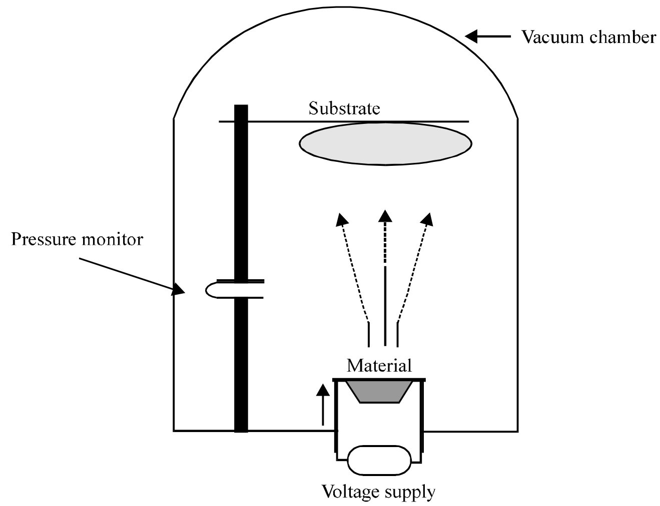

Fig. 1: Thermal evaporation setup

will be directly performed on the capillary tubes. Figure 1 shows the model thermal evaporation setup. A capillary tube is a hollow rod of glass tube through which thermal evaporation technique metal elements are deposited and are used as electrodes. Demori *et al.* (2010) used copper plates as electrodes. Capillary tubes of different size ranging from 5-10 mm is used and deposited with Al and Cu elements for studying and understanding the formation of capacitance. Demori *et al.* (2010) proposed plastic pipe for liquid flow. The main objective is to sense or measure the empty spaces (void fraction) in the liquid medium that flow through the capillary tube. In addition to capillary tube glass substrates were also used for thin film deposition which will be used to study structural, morphological and electrical properties using XRD, SEM and LCR-Z meter, respectively. Capacitive measurement is done by using the LCR-z meter.

EXPERIMENTAL METHOD

Glass substrates and capillary tubes are cleaned with soap water and distilled water and placed under acetone ultrasonication for 5 min. The cleaned substrates will be used for thermal deposition of metals Al and Cu (separately). The source materials Al and Cu are 99.99% pure. The vacum chamber is cleaned and evacuated to low pressure of 10^{-5} m bar using turbo molecular pump. The metal to be deposited (Al or Cu) is cleaned, weighed and placed in the tungsten filament. The tungsten filament is heated by applying a high potential. The metal element starts melting because of the heat produced by the filament. Voltage will be immediately raised higher at this junction in order to evaporate the melting metal. The evaporated vapour will be deposited in the glass substrate and capillary tube placed above the filament there by forming a thin film deposition on the substrates. The deposition is performed on room temperature. After deposition, the films were kept in the vacum chamber for about 30 min for uniform film temperature inside the chamber. The films were characterized for their structural properties using 'RIGAKU' XRD device, morphological properties using 'JEOL JSM 6710F' FE-SEM device and electrical properties like capacitance and resistance using 'KOKUYO electric KC605' LCR/Z meter.

RESULTS AND DISCUSSION

Structural analysis: The structural analysis of the Al and Cu deposited thin film were studied using XRD device from the Al XRD graph as given in Fig. 2, it can be clearly seen that there is no

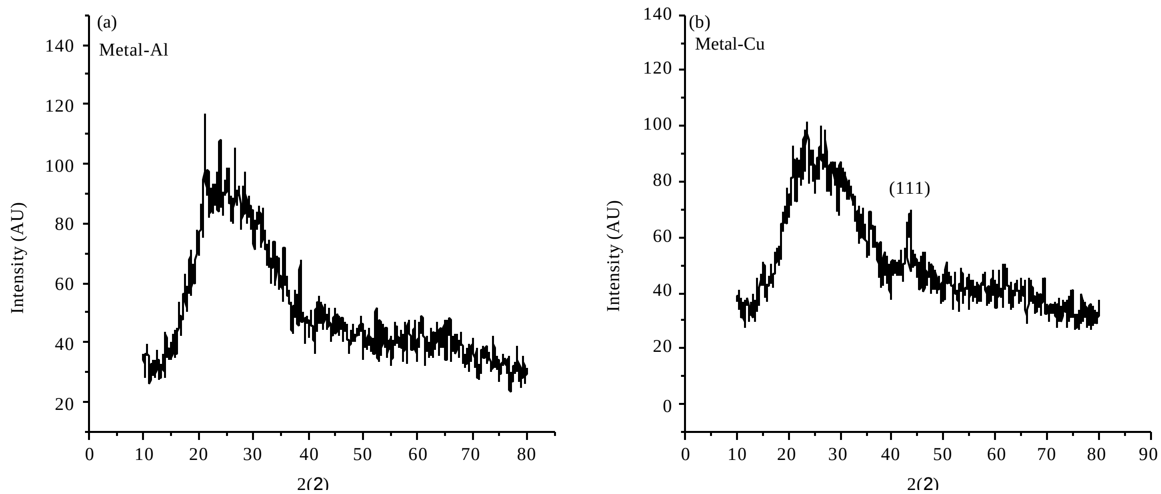

Fig. 2(a-b): XRD patterns of Aluminium (Al) and Copper (Cu) thin films

significant peak found and hence the film is amorphous in nature, this may due to fact that no additional energies were applied to growth of the film. The XRD pattern of Cu as given in Fig. 2, shows at 2θ value of 43.6 which is corresponding to (111) (Habibi *et al*., 2010) plane and the grain size is calculated using the Scherrer's equation:

$$D = (0.9\ \lambda)/(\beta\ \text{Cos}\ \theta)$$

where, 'λ' is 0.1541 nm, 'β' is FWHM (full width at half maximum), 'θ' is the diffraction angle and 'D' is particle diameter size and the crystal size is of the value 16.43 nm.

Morphological analysis: FE-SEM micrographs of Al and Cu deposited thin films were taken and is given in Fig. 3. The Al micrograph shows that grains aligned uniformly with less porous structure. The Cu micrograph shows that film has cracks which are because of the stress subjected on the film, when it is introduced to atmospheric condition.

Electrical properties: The sheet resistance of thin films is studied using 4 probe technique which gives more accurate measurements than 2 probe technique, in which constant current (mA) is applied for 2 probes and correspondingly voltage (mV) is measured in other 2 probes. An average resistance of 1.06Ω and 0.58Ω is obtained respectively, for Al and Cu which indicates that the deposited metal films are good conductors. Figure 4 shows V-I characteristic curve of Al and Cu thin films.

Capacitance measurement: Capacitance measurement is done between 2 metal electrodes using LCR meter as given in Fig. 5, in which a capacitance of 0.9 and 1.25 nF is obtained for Al and Cu, respectively. Capacitor arrangement is formed by placing substrate one above the other with electrode side facing outside. The LCR meter probe is placed on both the electrodes to measure the capacitance.

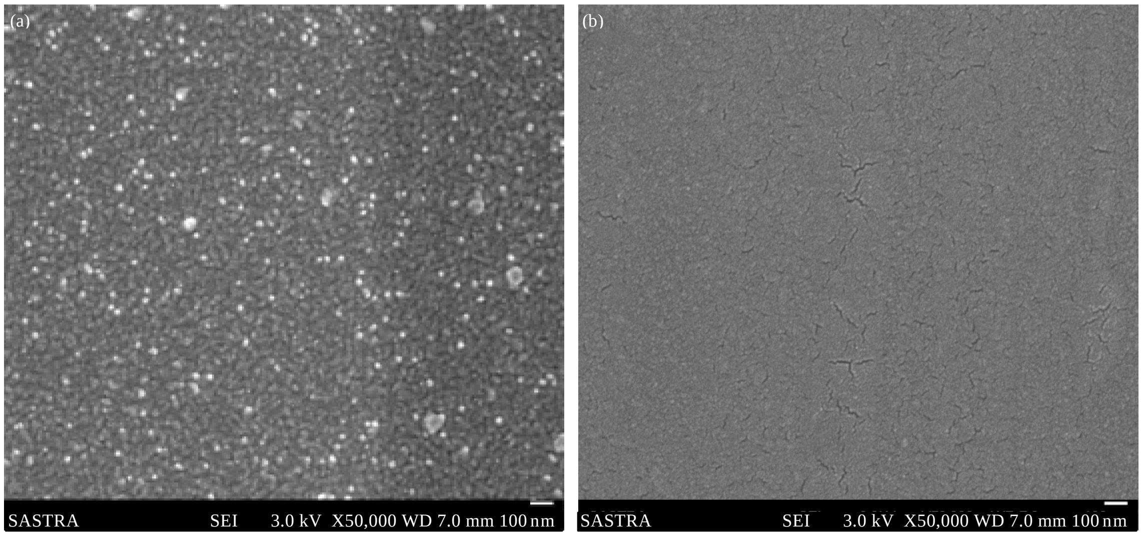

Fig. 3(a-b): FE-SEM micrographs of (a) Cu and (b) Al thin films

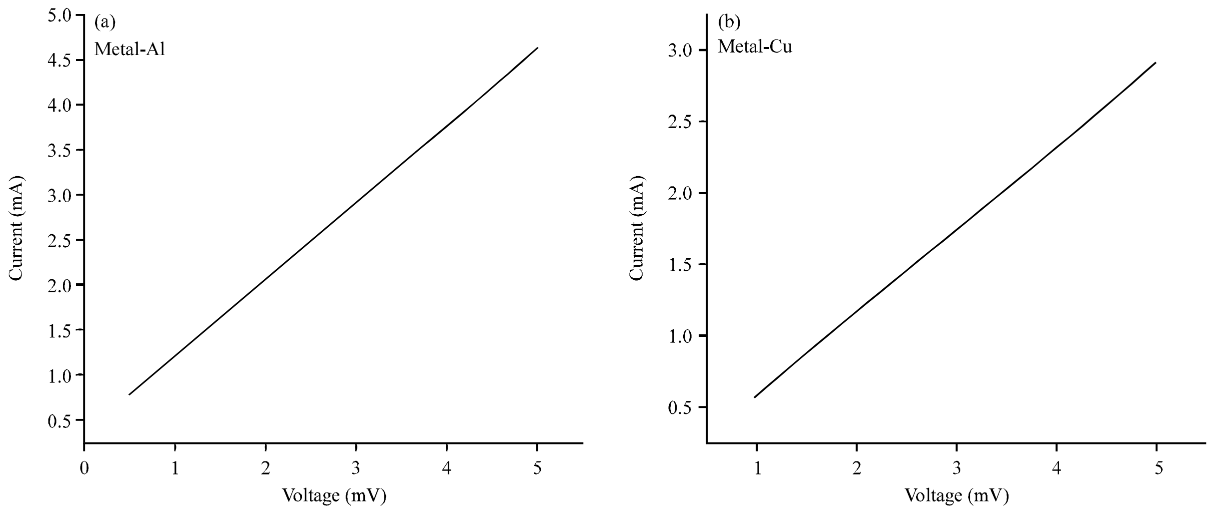

Fig. 4(a-b): V-I characteristic curve of (a) Al and (b) Cu thin films

Demori *et al*. (2010) measured capacitance in terms of voltage by incorporating the sensor with the amplifier. Jaworek *et al*. (2004) reported to have equivalent capacitance of 0.1-10 pF because of the small diameter of metal electrode for capacitance measurement incorporated in LC oscillator for RF measurement. Uesawa *et al*. (2012) measured void fraction in terms of electric resistivity or electric permittivity and this method can only be incorporated for conductive liquid flow. Zhu *et al*. (1991) reported the absolute capacitance of the sensor to be few or even less than 1 pF and the sensor is used for the displacement measurement application. Pranav *et al*. (2013) reported to have capacitance of 0.3763 pF for air and 47.66 pF for water.

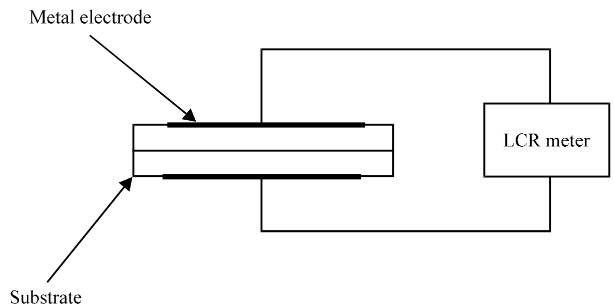

Fig. 5: Set up for capacitance measurement

CONCLUSION

The deposited Al and Cu thin films are studied for structural, morphological and electrical properties. The measured electrical resistance shows the formation of metal electrodes on the substrate and capacitance value shows the thin film can be used as capacitor.

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