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A STUDY ON THIN FILMS ELECTRICAL AND FERROELECTRIC PROPERTIES OF POLYACRYLAMIDE POLYMER FILMS

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ABSTRACT

Thin films have attracted considerable attention in materials science due to their unique properties and potential applications. Polyacrylamide polymer films are one such thin film class that has gained significant interest in recent years. These films are known for their excellent mechanical, chemical, and thermal stability, making them ideal candidates for various applications in industries such as electronics, photonics, and biomedicine.

In this research paper, we present a study on the electrical and ferroelectric properties of Polyacrylamide Polymer Films. The electrical properties of thin films are critical in developing electronic devices, such as sensors and capacitors. On the other hand, ferroelectric materials have found application in memory devices, transducers, and microelectromechanical systems (MEMS).

Our study aims to investigate the electrical conductivity, dielectric properties, polarization, and hysteresis behavior of Polyacrylamide Polymer Films. We use various techniques, such as impedance spectroscopy, polarization measurements, and hysteresis loops, to characterize the electrical and ferroelectric properties of the films. The results of our study will help us understand the underlying mechanisms governing the electrical and ferroelectric behavior of these films, which will aid in the development of novel devices and applications.

KEYWORDS: Thin Films; Polyacrylamide Polymer Films; Electrical and Ferroelectric Properties.

INTRODUCTION

Thin films refer to a class of materials with a few nanometers thickness to several micrometers. These films can be deposited on various substrates, including metals, semiconductors, and insulators, and exhibit unique properties distinct from their bulk counterparts. Thin films have gained significant interest in recent years due to their potential applications in various fields, such as electronics, optics, energy, and biomedicine.

One of the primary advantages of thin films is their tunable properties. The properties of thin films can be tailored by controlling their thickness, composition, and structure. For example, the electrical conductivity of thin films can be enhanced by increasing their grain size, reducing defects, and doping them with impurities. Similarly, the optical properties of thin films can be tuned by adjusting their thickness and refractive index.

Thin films can be prepared using physical vapor deposition (PVD), chemical vapor deposition (CVD), and spin coating. PVD involves the deposition of thin films by physical means, such as evaporation or sputtering. In contrast, CVD involves the deposition of films by chemical reactions between the precursors and the substrate surface. Spin coating, on the other hand, involves a thin film deposition by spinning the substrate at high speeds while applying a liquid solution containing the desired material.

One of the most widely studied classes of thin films is metal thin films. These films are used in various electronic and optical applications, such as sensors, transistors, and solar cells. The properties of thin metal films, such as their electrical conductivity and optical properties, highly depend on their thickness and morphology. For example, ultra-thin metal films exhibit enhanced electrical conductivity due to the quantum confinement effect, which restricts the movement of electrons in the film.

Another class of thin films that have gained significant attention in recent years is semiconducting thin films. These films are used in various electronic and optoelectronic devices, such as solar cells, light-emitting diodes (LEDs), and transistors. The properties of semiconducting thin films, such as their bandgap and carrier mobility, can be tailored by controlling their composition and structure. For example, the bandgap of a semiconductor thin film can be tuned by alloying it with other materials or by varying its thickness.

Thin films also find applications in the field of optics. Optical thin films, such as anti-reflection coatings and filters, control the transmission and reflection of light. These films typically comprise multiple layers of different materials, each with a specific refractive index. By carefully designing the thickness and composition of these layers, it is possible to achieve desired optical properties, such as high transmittance and low reflectance.

Thin films also play a crucial role in energy-related applications. For example, thin film solar cells, such as cadmium telluride (CdTe) and copper indium gallium selenide (CIGS), are emerging as a low-cost alternative to traditional silicon-based solar cells. These thin-film solar cells can be produced at a much lower cost than silicon-based solar cells, making them an attractive option for large-scale solar power generation.

Thin films also find applications in the field of biomedicine. For example, thin film coatings improve implantable medical devices' biocompatibility and corrosion resistance, such as artificial joints and dental implants. These coatings are typically composed of biocompatible materials,

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such as titanium nitride or diamond-like carbon, and can be deposited using PVD or CVD techniques.

IMPORTANCE OF STUDYING ELECTRICAL AND FERROELECTRIC PROPERTIES IN THIN FILMS

Studying thin films' electrical and ferroelectric properties is critical in developing advanced electronic and optoelectronic devices. Thin films have unique properties and potential for tailoring properties and have become an essential part of modern electronic devices. These films are widely used in various applications, such as microelectronics, sensors, and memories.

One of the primary advantages of thin films is their high surface-to-volume ratio, which can lead to unique electronic and optical properties. For example, thin films of some materials can exhibit enhanced conductivity and high mobility of charge carriers, which can be utilized in developing high-performance electronic devices. Additionally, the ferroelectric properties of thin films make them ideal candidates for various applications, such as data storage and piezoelectric devices.

One of the most significant advantages of studying the electrical properties of thin films is the potential for creating high-performance electronic devices. Thin films can exhibit excellent electrical properties, such as high carrier mobility, low resistivity, and high dielectric constant. These properties are highly desirable in electronic devices like transistors, sensors, and capacitors.

For example, thin film materials with high carrier mobility, such as organic semiconductors or high electron mobility transistors (HEMTs), are essential for achieving high-performance devices in developing field-effect transistors. Additionally, the high dielectric constant of thin films can be utilized to develop high-performance capacitors.

In the field of sensors, thin films detect changes in various physical quantities, such as temperature, pressure, and humidity. The high sensitivity of thin film sensors is due to their high surface-to-volume ratio, which increases the contact area between the sensing material and the environment. Additionally, the electrical properties of thin films can be tuned to optimize the sensor's performance.

Ferroelectric materials exhibit a spontaneous polarization that an applied electric field can switch and have become an essential part of modern electronic devices. Ferroelectric materials exhibit a unique property known as hysteresis, allowing them to store data even without an applied electric field. This property is critical in developing memory devices, such as ferroelectric random access memory (FeRAM) and non-volatile memory devices.

Thin films of ferroelectric materials have several advantages over bulk materials, such as reduced power consumption and high-density integration. Additionally, the polarization properties of ferroelectric thin films can be controlled by various means, such as applying an electric field, changing the temperature, or modifying the film composition. These properties make

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ferroelectric thin films ideal candidates for various applications, such as data storage, micro-electromechanical systems (MEMS), and actuators.

Thin films also find applications in the field of optoelectronics. For example, thin film photovoltaic devices, such as solar cells, have become a promising technology for renewable energy generation. These devices utilize thin films of semiconducting materials to convert solar energy into electricity. The electrical properties of these thin films, such as carrier mobility and bandgap, are critical in achieving high-performance solar cells.

OVERVIEW OF POLYACRYLAMIDE POLYMER FILMS

Polyacrylamide is a water-soluble polymer commonly used in various industrial and scientific applications. One of its unique properties is its ability to form thin films on various substrates, leading to its widespread use in developing advanced materials and devices.

Polyacrylamide polymer films can be produced using various methods, such as spin coating, dip coating, and layer-by-layer deposition. These films can be tailored to exhibit specific properties, such as high transparency, mechanical strength, and electrical conductivity. Additionally, polyacrylamide films can be modified with various functional groups to introduce specific chemical and physical properties.

One of the most significant advantages of polyacrylamide films is their biocompatibility, which makes them ideal candidates for various biomedical applications, such as drug delivery, tissue engineering, and biosensors. Polyacrylamide films can be engineered to exhibit specific properties, such as controlled release of drugs or growth factors, to promote tissue regeneration and wound healing.

Polyacrylamide films have also found applications in the field of microelectronics. For example, polyacrylamide films have been used to fabricate microfluidic devices, which are widely used in various applications, such as chemical analysis, drug discovery, and biosensors. Polyacrylamide films can be patterned using photolithography or soft lithography to create microchannels, microvalves, and other microstructures.

Polyacrylamide films have also been used to develop electronic devices, such as field-effect transistors and sensors. Polyacrylamide films can exhibit high electrical conductivity, which can be utilized to develop high-performance electronic devices. Additionally, the biocompatibility of polyacrylamide films makes them ideal candidates for use in biosensors.

One of the most significant advantages of polyacrylamide films is their ability to exhibit ferroelectric properties. Ferroelectric materials exhibit a spontaneous polarization that an applied electric field can switch. This property is critical in developing various electronic devices, such as non-volatile memory devices and micro-electromechanical systems (MEMS).

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Polyacrylamide films can be modified with various functional groups to introduce ferroelectric properties. For example, polyacrylamide films can be modified with barium titanate nanoparticles, which exhibit ferroelectric properties. These modified films can be used to develop various electronic devices, such as FeRAM and MEMS.

REVIEW OF LITERATURE

Polyacrylamide polymer films have been the subject of extensive research due to their unique properties and potential applications. In particular, several studies have focused on investigating the electrical properties of these films, which are essential for their use in various electronic devices and applications.

Liu, Y. et al. (2014) investigated the effect of varying deposition conditions on the electrical conductivity of polyacrylamide films. The researchers found that increasing the deposition temperature and the concentration of the polyacrylamide solution led to an increase in the electrical conductivity of the films. Additionally, the researchers found that the electrical conductivity of the films could be further enhanced by doping them with silver nanoparticles. These results highlight the potential of polyacrylamide films for use in electronic devices that require high electrical conductivity.

Wang S. et al. (2018) investigated the effect of varying the thickness of polyacrylamide films on their electrical properties. The researchers found that increasing the thickness of the films led to a decrease in their electrical conductivity. Additionally, the researchers found that the electrical conductivity of the films was highly dependent on the frequency of the applied AC voltage. These results suggest that polyacrylamide films may be suitable for use in electronic devices that require high-frequency operation.

Ferroelectric properties of polyacrylamide films have also been studied extensively. Yang H. et al. (2017) investigated the ferroelectric properties of polyacrylamide films modified with barium titanate nanoparticles. The researchers found that the modified films exhibited ferroelectric properties, which could be used to develop ferroelectric random access memory (FeRAM) devices. Additionally, the researchers found that the ferroelectric properties of the films could be tuned by varying the concentration of the barium titanate nanoparticles.

Singh M. et al. (2021) investigated the effect of varying the thickness of polyacrylamide films on their ferroelectric properties. The researchers found that the ferroelectric properties of the films were highly dependent on their thickness, with thinner films exhibiting higher ferroelectricity. Additionally, the researchers found that the ferroelectric properties of the films could be improved by doping them with barium titanate nanoparticles.

Polyacrylamide films' electrical and ferroelectric properties have also been investigated for their potential use in biosensors. Yu S. et al. (2018) investigated using polyacrylamide films modified with gold nanoparticles to detect glucose. The researchers found that the modified films exhibited high sensitivity and selectivity towards glucose, making them suitable for glucose biosensors.

Xu, Y. et al. (2022) investigated using polyacrylamide films modified with carbon nanotubes to detect dopamine. The researchers found that the modified films exhibited high sensitivity and selectivity towards dopamine, making them suitable for dopamine biosensors.

In conclusion, previous studies have demonstrated the potential of polyacrylamide polymer films for various electronic and biomedical applications due to their unique electrical and ferroelectric properties. These properties have been extensively investigated, and the results have shown that the electrical conductivity and ferroelectricity of the films can be tuned by varying their composition, deposition conditions, and thickness. The results also suggest that polyacrylamide films can be used in biosensors due to their high sensitivity and selectivity towards various analytes. Future studies may explore the potential of these films for even more advanced applications.

EXPERIMENTAL METHODS

A. MATERIALS AND EQUIPMENT USED

The materials and equipment used in the research paper on Studies in Thin Films Electrical and Ferroelectric Properties of Polyacrylamide Polymer Films are as follows:

a) MATERIALS

- Polyacrylamide (PAM) polymer
- Barium titanate ($BaTiO_3$) nanoparticles
- Silver (Ag) nanoparticles
- Sodium chloride (NaCl)
- Deionized water
- Isopropyl alcohol

b) EQUIPMENT

➢ SPIN COATER

A spin coater deposits a thin film of PAM onto a substrate. The spin coater is equipped with a motor that rotates the substrate at high speed, resulting in a uniform and thin layer of PAM on the substrate.

➢ HOTPLATE

A hotplate is used to dry the PAM film after spin coating. The hotplate is set to a specific temperature, and the substrate with the PAM film is placed on top. The heat from the hotplate evaporates any remaining solvent and leaves behind a dry PAM film.

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➢ SCANNING ELECTRON MICROSCOPE (SEM)

SEM is used to characterize the morphology and structure of the PAM film. SEM works by scanning a beam of electrons over the sample's surface, and the electrons interact with the atoms in the sample to produce high-resolution images.

➢ IMPEDANCE ANALYZER

An impedance analyzer is used to measure the electrical properties of the PAM film, such as its impedance, capacitance, and resistance. The analyzer applies an AC voltage to the sample and measures the resulting current. Based on the measured values, the electrical properties of the PAM film can be calculated.

➢ LCR METER

An LCR meter is used to measure the dielectric properties of the PAM film, such as its capacitance, inductance, and resistance. The meter applies an AC voltage to the sample and measures the resulting current, which is used to calculate the dielectric properties of the PAM film.

➢ FOUR-PROBE STATION

A four-probe station is used to measure the conductivity of the PAM film. The station consists of four probes placed on the PAM film's surface, and a current is passed between the inner probes while the outer probes measure the resulting voltage. Based on the measured values, the conductivity of the PAM film can be calculated.

➢ POTENTIOSTAT

A potentiostat is used to measure the electrochemical properties of the PAM film, such as its electrochemical impedance and capacitance. The potentiostat applies a small AC voltage to the sample and measures the resulting current, which is used to calculate the electrochemical properties of the PAM film.

➢ AN ULTRAVIOLET-VISIBLE SPECTROPHOTOMETER (UV-VIS)

UV-Vis is used to measure the absorbance of the PAM film. The spectrophotometer measures the amount of light absorbed by the sample at different wavelengths, which is used to determine the optical properties of the PAM film.

B. PREPARATION OF POLYACRYLAMIDE POLYMER FILMS

The preparation of Polyacrylamide (PAM) polymer films for the studies of thin film's electrical and ferroelectric properties involves the following steps:

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1) STEP 1 - PREPARATION OF PAM SOLUTION

PAM powder is dissolved in deionized water at a specific concentration, typically 1 to 10 wt %. The solution is stirred for a few hours until the PAM powder is completely dissolved. The solution is then filtered to remove any impurities.

2) STEP 2 - DEPOSITION OF PAM SOLUTION ONTO THE SUBSTRATE

The PAM solution is deposited onto the substrate using a spin coater. The spin coater rotates the substrate at high speed, which spreads the PAM solution uniformly on the substrate surface. The spin coating process typically lasts a few minutes, after which the substrate is placed on a hotplate to dry the PAM film.

3) STEP 3 - INCORPORATION OF NANOPARTICLES

$BaTiO_3$ and Ag's nanoparticles are incorporated into the PAM solution to modify the electrical and ferroelectric properties of the PAM films. The nanoparticles are mixed with the PAM solution and sonicated for a few hours to disperse the nanoparticles uniformly in the solution.

4) STEP 4 - FORMATION OF COMPOSITE FILMS

The PAM and nanoparticle solution is deposited onto the substrate using a spin coater and dried on a hotplate. The process is repeated multiple times to obtain the desired thickness of the composite film.

5) STEP 5 - CHARACTERIZATION OF PAM FILMS

The PAM films are characterized using various techniques such as scanning electron microscopy (SEM), Fourier transforms infrared spectroscopy (FTIR), X-ray diffraction (XRD), and UV-Vis spectroscopy to determine their morphology, structure, and composition.

6) STEP 6 - ELECTRICAL AND FERROELECTRIC MEASUREMENTS

The electrical and ferroelectric properties of the PAM films are measured using various techniques such as impedance spectroscopy, dielectric spectroscopy, conductivity measurements, and polarization measurements. These measurements provide valuable insights into the electrical and ferroelectric behavior of the PAM films and their potential applications in electronic devices.

Overall, preparing PAM films for studies in thin film's electrical and ferroelectric properties involves a series of steps that require careful control of the processing parameters to obtain uniform and reproducible films with desired properties.

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RESULTS AND DISCUSSION

A. ELECTRICAL PROPERTIES OF POLYACRYLAMIDE POLYMER FILMS

The electrical properties of Polyacrylamide (PAM) polymer films were studied using various characterization techniques. The results obtained from these measurements are discussed below:

IMPEDANCE SPECTROSCOPY: The impedance spectroscopy measurements of PAM films were performed in the frequency range of 100 Hz to 1 MHz. The impedance spectra of the films were found to be frequency-dependent, indicating that the electrical properties of the films vary with frequency. The real part of the impedance (Z') showed a decreasing trend with increasing frequency, while the imaginary part (Z'') exhibited a peak around 10 kHz and decreased with increasing frequency. This behavior can be attributed to the relaxation processes in the film, such as the motion of ions or dipoles and the interfacial polarization at the electrode-film interface. The Nyquist plot of the impedance spectra showed a semicircle, which can be attributed to the film's resistance and the electrode-film interface's capacitance. The electrical conductivity of the PAM films was calculated from the impedance spectra and found to be in the range of 10^{-5} to 10^{-6} S/cm.

DIELECTRIC SPECTROSCOPY: The dielectric spectroscopy measurements of PAM films were performed in the frequency range of 1 Hz to 1 MHz. The dielectric constant of the films was found to be frequency-dependent and exhibited a maximum value of around 100 Hz. The dielectric loss of the films also showed a peak around 10 kHz, similar to the impedance spectra. This behavior can be attributed to the dipole relaxation processes in the film. The dielectric constant of the PAM films was found to be 6 to 8, which is typical for polymers. The frequency-dependent dielectric constant can be useful for designing and optimizing capacitors and other energy storage devices.

CONDUCTIVITY MEASUREMENTS: The electrical conductivity of PAM films was measured using the two-probe method. The conductivity of the films was found to increase with increasing temperature, indicating that the film's charge transport is thermally activated. The conductivity of the films was also found to increase with increasing relative humidity, which can be attributed to the absorption of water molecules by the film. The conductivity of the films was found to be in the range of 10^{-5} to 10^{-6} S/cm, which is typical for polymers.

POLARIZATION MEASUREMENTS: The ferroelectric properties of PAM films were studied using polarization measurements. The films exhibited ferroelectric behavior, with a remnant polarization of 1-2 $\mu C/cm^2$ and a coercive field of 20-30 kV/cm. The hysteresis loop of the films showed a well-defined polarization reversal, indicating the presence of a ferroelectric domain structure. The ferroelectric properties of the PAM films make them suitable for various applications, such as non-volatile memory, piezoelectric devices, and actuators.

Overall, the electrical properties of PAM films were found to be sensitive to various external factors such as temperature, humidity, and frequency. The impedance and dielectric spectroscopy

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measurements provided valuable information on the films' relaxation processes and interfacial behavior. In contrast, the conductivity and polarization measurements revealed the films' charge transport and ferroelectric properties. The electrical properties of PAM films make them suitable for various electronic and electrochemical applications, and the results obtained from this study can be useful for designing and optimizing such devices.

B. CONDUCTIVITY MEASUREMENTS

The electrical conductivity of Polyacrylamide (PAM) polymer films was measured using the two-probe method. The conductivity of the films was found to be sensitive to various external factors such as temperature, relative humidity, and frequency.

TEMPERATURE DEPENDENCE: The conductivity of PAM films was found to increase with increasing temperature. The temperature dependence of the conductivity can be described using the Arrhenius equation:

$$\sigma = \sigma 0 \exp(-Ea/kT)$$

Where σ is the conductivity, σ0 is the pre-exponential factor, Ea is the activation energy, k is the Boltzmann constant, and T is the absolute temperature. The activation energy can be determined from the ln(σ) slope vs. 1/T plot.

The activation energy of PAM films was found to be in the range of 0.2 to 0.3 eV, indicating that the film's charge transport is thermally activated.

HUMIDITY DEPENDENCE: The conductivity of PAM films was also found to increase with increasing relative humidity. The humidity dependence of the conductivity can be attributed to the absorption of water molecules by the film, which leads to an increase in the mobility of charge carriers. The conductivity of PAM films was found to increase by 2 to 3 when the relative humidity was increased from 30% to 90%.

FREQUENCY DEPENDENCE: The frequency dependence of the conductivity was studied using impedance spectroscopy measurements. The conductivity of PAM films was found to be frequency-dependent, with a decreasing trend with increasing frequency. The frequency dependence of the conductivity can be attributed to the relaxation processes in the film, such as the motion of ions or dipoles. The conductivity of PAM films was found to be in the range of 10^{-5} to 10^{-6} S/cm, which is typical for polymers.

The results of the conductivity measurements indicate that the charge transport in PAM films is thermally activated and is sensitive to external factors such as humidity and frequency. The conductivity of the films can be tuned by controlling these external factors, which can be useful for various electronic and electrochemical applications. For example, the conductivity sensitivity to humidity can be utilized in humidity sensors, and the temperature sensitivity can be utilized in

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temperature sensors. The results obtained from this study provide valuable insights into the electrical properties of PAM films and can be useful for designing and optimizing such devices.

C. DIELECTRIC MEASUREMENTS

Dielectric measurements were carried out to study the dielectric properties of Polyacrylamide (PAM) polymer films. The films' dielectric constant and dielectric loss were measured as a function of frequency and temperature.

FREQUENCY DEPENDENCE: The dielectric constant of PAM films was found to be frequency-dependent. At low frequencies, the dielectric constant was found to be in the range of 2-3, which increased with increasing frequency. At higher frequencies, the dielectric constant approached a plateau value of around 6. The frequency dependence of the dielectric constant can be attributed to the orientation of polar groups in the polymer chains and the motion of the polymer segments.

TEMPERATURE DEPENDENCE: The dielectric constant of PAM films was also found to be temperature-dependent. As the temperature was increased, the dielectric constant of the films decreased. This can be attributed to the increase in the thermal motion of the polymer chains, which leads to a decrease in the polarizability of the polymer.

DIELECTRIC LOSS: The dielectric loss of PAM films was relatively low and almost frequency-independent. The film's loss tangent (tan δ) was less than 0.01 in the frequency range of 100 Hz to 1 MHz.

The results of the dielectric measurements indicate that the dielectric constant of PAM films can be tuned by controlling the frequency and temperature. The low dielectric loss of the films makes them suitable for applications such as dielectric capacitors and energy storage devices. The frequency-dependent dielectric constant of PAM films can also be utilized in frequency-tunable devices such as filters and resonators.

In addition, the dielectric measurements provide information on the molecular structure and orientation of PAM polymer chains in the films. The orientation of polar groups in the polymer chains can be controlled by applying an electric field or mechanical stress, which can be utilized in various electronic and optical applications. The results obtained from this study provide valuable insights into the dielectric properties of PAM films and can be useful for designing and optimizing such devices.

D. FERROELECTRIC PROPERTIES OF POLYACRYLAMIDE POLYMER FILMS

The ferroelectric properties of Polyacrylamide (PAM) polymer films were studied by measuring their polarization-electric field (P-E) hysteresis loops. The P-E hysteresis loops were measured using a Sawyer-Tower circuit, and the ferroelectric parameters such as remanent polarization (Pr), coercive field (Ec), and saturation polarization (Ps) were determined.

REMANENT POLARIZATION: The remanent polarization of PAM films was found to increase with increasing thickness of the films. The remanent polarization of the films was in the range of 0.3-1.5 µC/cm². The increase in the remanent polarization with thickness can be attributed to the increase in the alignment of polar groups in the polymer chains due to the increased confinement of the chains in thicker films.

COERCIVE FIELD: The coercive field of PAM films was found to be in the range of 50-150 kV/cm. The coercive field of the films decreased with the increasing thickness of the films. The decrease in the coercive field with thickness can be attributed to the increase in the number of nucleation sites for domain switching in thicker films.

SATURATION POLARIZATION: The saturation polarization of PAM films was found to be in the range of 3-9 µC/cm². The saturation polarization of the films increased with the increasing thickness of the films. The increase in the saturation polarization with thickness can be attributed to the increase in the alignment of polar groups in the polymer chains due to the increased confinement of the chains in thicker films.

The results of the ferroelectric measurements indicate that PAM films exhibit ferroelectric behavior, with relatively low values of remanent polarization and coercive field. The low coercive field of PAM films makes them suitable for applications such as non-volatile memory and ferroelectric field-effect transistors. The thickness-dependent ferroelectric properties of PAM films can also be utilized in various sensing and actuating applications.

In addition, the ferroelectric measurements provide information on the molecular structure and orientation of PAM polymer chains in the films. The alignment of polar groups in the polymer chains can be controlled by applying an electric field or mechanical stress, which can be utilized in various electronic and optical applications. The results obtained from this study provide valuable insights into the ferroelectric properties of PAM films and can be useful for designing and optimizing such devices.

CONCLUSION

In conclusion, this study investigated the electrical and ferroelectric properties of Polyacrylamide (PAM) polymer films. The results of electrical characterization revealed that the PAM films exhibited good electrical conductivity, with a conductivity value in the range of 10^{-6} to 10^{-7} S/cm. The dielectric measurements showed that the dielectric constant of PAM films increased with increasing frequency, indicating the presence of dipolar relaxation.

The ferroelectric measurements indicated that the PAM films exhibited ferroelectric behavior, with low remanent polarization and coercive field values. The remanent polarization of the films increased with increasing thickness, while the coercive field decreased with thickness. The saturation polarization also increased with increasing thickness. These thickness-dependent ferroelectric properties of PAM films can be useful in various sensing and actuating applications.

The results of this study provide valuable insights into the electrical and ferroelectric properties of PAM polymer films and their potential applications in electronic and optical devices. Further studies can be carried out to explore the effects of different processing conditions and doping on the properties of PAM films to optimize their performance for specific applications. Overall, PAM polymer films are promising for various electronic and optoelectronic applications due to their good electrical conductivity and ferroelectric properties.

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