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ELECTRICAL AND DIELECTRIC CHARACTERISTICS OF ANNEALED MUSCOVITE RUBY MICA

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Abstract. The electrical and dielectric response of muscovite ruby mica has been investigated by measuring various parameters (Impedance, Impedance phase angle, Susceptance, Admittance, Dissipation factor or tanδ, Quality factor, Static capacitance in series-equivalent circuit mode, Static capacitance in parallel-equivalent circuit mode) as a function of frequency (range between ~10 MHz to 120 MHz) at different annealing temperature (range between room temperature to 1050 ^{o}C). The present work reveals the influence of thermal treatment on the electrical/dielectric characteristics of muscovite ruby mica. The high temperature annealed mica shows approximately 72% low quality factor as compared to the unannealed mica. This paper will be helpful for the better utilization of muscovite in various high temperature and frequency equipments.

1. Introduction

There are several kinds of minerals, with different properties, but mica is in general very stable and has many tremendous applications in science and technology (especially high voltage and temperature) [1-11]. Mica has the interesting property that its complex crystalline, asymmetrical and anisotropic lattice environs affect various properties with respect to different orientations [12-14]. It has a distinct layered structure, and it is possible to split or cleave mica into very thin, optically flat, sheets. There are many types of mica, but some important common rock-forming minerals (e.g., muscovite, biotite, phlogopite etc.) have unique properties [10-14]. These types of micas have low dielectric loss, a perfect cleavage, high flexibility, and good physico-chemical stability both at high temperatures and high electric fields. Mica capacitors are normally made from muscovite mica, or potassium aluminium silicate. Mica capacitors have high Q or small power factors that may be quite frequency and temperature dependent. Although the high temperature response of muscovite mica has been studied by various authors [10-11, 15-16], it is important to obtain information about high temperature behaviour by the measurements of some electrical/dielectric characteristics of muscovite mica as a function of frequency and temperature. Apart from few work on electrical and dielectric properties of mica [12, 17-22], we could not find more information on the electrical/dielectric properties of annealed mica, and in particular muscovite mica. This type of investigation provides information for various industrial applications and as well as the better understanding of the various high temperature transformations of muscovite mica. In the present work, various electrical and dielectric properties (Impedance, Impedance phase angle, Susceptance, Admittance, Dissipation factor or tanδ, Quality factor, Static capacitance in series-equivalent circuit mode and Static capacitance in parallel-equivalent circuit mode) of high temperature annealed muscovite mica as a function of frequency have been investigated. To best of our knowledge the present electrical/dielectric characteristics have never been conducted on muscovite mica as a function of temperature (Room temperature to 1050 ^oC) and frequency ~10 MHz-120 MHz.

2. Materials and method

Minerals consist of negatively charged silicate layers bonded together by interlayer cations. Mica belongs to a family of minerals known as phyllosilcates has a monoclinic structure with unit structure of one octahedral sheet sandwiching between two tetrahedral sheets. Due to its layered crystalline structure it can be cleaved easily into thin translucent sheets. These sheets form a layer that is separated from adjacent layers by planes of non-hydrated interlayer cations [13-14].

In the present investigation, sheets of natural muscovite ruby mica (0.006”- 0.009”) were collected from Precision Pressed Products, New Delhi, India. Muscovite mica has layered structure of series of sheets stacked parallel to each other. It consists of infinite sheets of corner-shared SiO_4 tetrahedra, with the apical oxygen atoms located at the corners of a hexagon. In the structure of muscovite mica, $1/4^{th}$ Silicon is replaced by Aluminium, with the remaining Al^{3+} and K^+ ions lying between the aluminosilicate sheets. AlO_6 octahedral sheet is sandwiched between two SiO_4 tetrahedral sheets, with K^+ ions located between the trilayer aluminosilicate sheets. Mica cleaves rather easily because of the weak ionic bonding between the K^+ layers and the trilayer aluminosilicate sheet [13-14]. Muscovite mica has a high dielectric strength and excellent stability, making it a favoured material for manufacturing capacitors for radio frequency applications. It has also been used as an insulator in high voltage electrical and high temperature equipments. It is also birefringent and is commonly used to make quarter and half wave plates. Micas have a low cation exchange capacity for 2:1 clays. K+ ions between layers of mica prevent swelling by blocking water molecules. For high power, high voltage, and high frequency applications, such as an antenna capacitor in an AM broadcast stations, the muscovite ruby mica seems to be the best. The lower the dielectric loss (proportion of energy lost as heat), the more effective is a dielectric mica material.

The thin mica sheets were annealed with different temperature for two hours and then cooled gradually. A commercial 3535 LCR Hitester by HIOKI was used to measure different electrical and dielectric parameters of annealed (temperature ranges from room temperature to 1050 ^oC) muscovite ruby mica as a function of frequency (range from ~10 MHz to 120 MHz).

3. Results and discussion

Different electrical and dielectric properties (Impedance, Impedance phase angle, Susceptance, Admittance, Dissipation factor or tanδ, Quality factor, Static capacitance in series-equivalent circuit mode and Static capacitance in parallel-equivalent circuit mode) of muscovite ruby mica as a function of frequency (range from ~10 MHz to 120 MHz) at varying annealing temperatures (RT-1050 ^oC) are presented in Figs. 1-8.

Impedance is a complex parameter and present in all circuits and components due to its universal quality. When alternating current goes through it, a voltage drop is produced that is somewhere 0^0 and 90^0 out of phase with the current. The impedance phase angle for any component is the phase shift between voltage across that component and current through that component. For a perfect inductor, voltage drop always leads current by 90^0, and so an inductors impedance phase angle is said to be $+90^0$. For a perfect capacitor, voltage drop always lags current by 90^0, and so a capacitor’s impedance phase angle is said to be -90^0. In order to express the quantitative effects of mixed resistive and reactive components, impedance will be useful. Impedance of a muscovite ruby mica as a function of frequency at different annealing temperatures is shown in Fig. 1. From Fig. 1, it is observed that at lower region of frequency, the impedance varies significantly with frequency. The impedance increases as the annealing temperature increases from room temperature to 1050 ^oC, and the impedance varies abruptly during the temperature interval of 600 to 700 °C. The impedance for all the temperature decreases with increasing frequency and show approximately the same value at frequency ~107 MHz, and after this point the impedance pattern changes and it decreases with increasing annealing temperature. There is a shoulder in the impedance curve near ~19-20 MHz and increases with increasing temperature. The frequency behaviour of impedance phase angle (θ) for muscovite ruby mica at different annealing temperatures is shown in Fig. 2. Figure 2 clearly shows that, in the frequency range of ~10-20 MHz, impedance phase angle decreases and then increases abruptly up to 35 MHz, and again decreases up to 38 MHz. After 38 MHz, it increases up to 60 MHz and then decreases up to 86-87 MHz and then again increases for higher frequencies. As figure shows there is an abrupt change in impedance phase angle in annealing temperature interval 600 to 700 °C.

Reactive components such as inductors and capacitors oppose the flow of electrons with respect to time, rather than with a constant, unchanging friction as resistors do. We call this time-based opposition reactance. As conductance is the component of resistance, there is also a complementary expression of reactance, called susceptance, and it is the reciprocal of reactance. Reactance is the measure of how much a circuit reacts against change in current over time and susceptance is the measure of how much a circuit is susceptible to conducting a changing current. Like conductance, susceptance adds in parallel and diminishes in series and is a scalar quantity. Conductance and susceptance are most useful in circuits where the resistive and reactive opposition are not mixed i.e., either a purely resistance (conductive), or a purely reactive (susceptive) circuit. Figure 3 presents the susceptance as a function of frequency at different annealing temperatures for muscovite ruby mica. There is a slight variation in susceptance with temperature and it shows higher value for higher temperature as compared to lower one. The susceptance increases as the temperature increases up to ~105-110 MHz region of frequency. At this frequency the susceptance for all the annealing temperatures shows approximately the similar behaviour and after this the susceptance pattern became reverse similar as observed in impedance i.e., the susceptance increases as the annealing temperature increases. Figure also shows the abrupt change in susceptance during the temperature interval of 600 to 700°C. At higher frequency (above 110 MHz), high-temperature annealed muscovite ruby mica shows higher susceptance as compared to lower temperature.

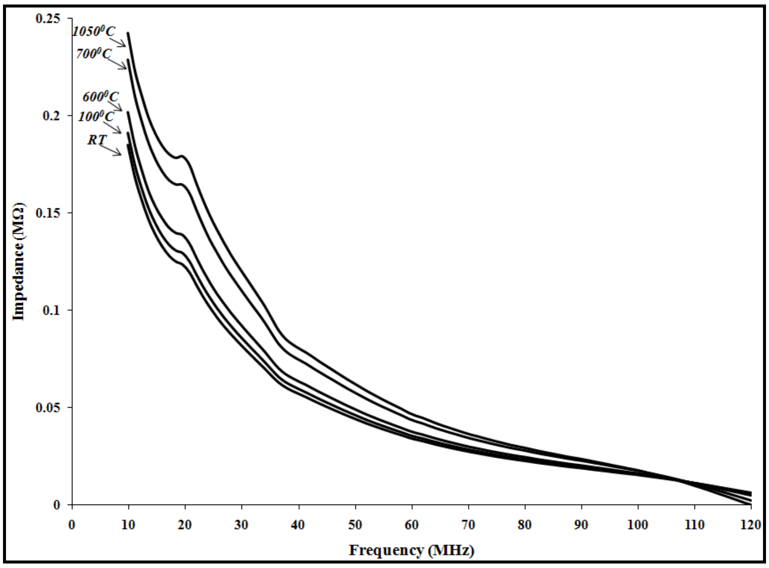

Fig. 1. Impedance of muscovite ruby mica annealed at different temperatures.

Admittance (reciprocal of impedance) is measured in units of Siemens. Impedance is a measure of how much alternating current is impeded or hindered in a circuit, admittance is a measure of how much current is admitted. The frequency behaviour of admittance of muscovite ruby mica at different annealing temperatures (RT to 1050 ^{o}C) is presented in Fig.4. Figure shows the increase in admittance with the increase of frequency up to ~110MHz. In this frequency range there is no significant effect of annealing temperature on the admittance. After 110 MHz, the admittance increases as the annealing temperature increases from RT to 1050 ^{o}C with abrupt change during the temperature interval 600 ^{o}C-700 ^{o}C.

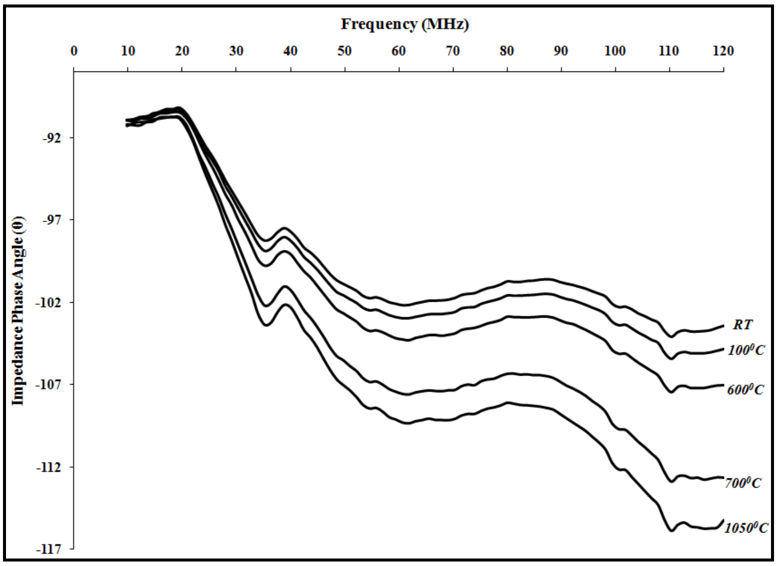

Fig. 2. Impedance phase angle of muscovite ruby mica annealed at different temperatures.

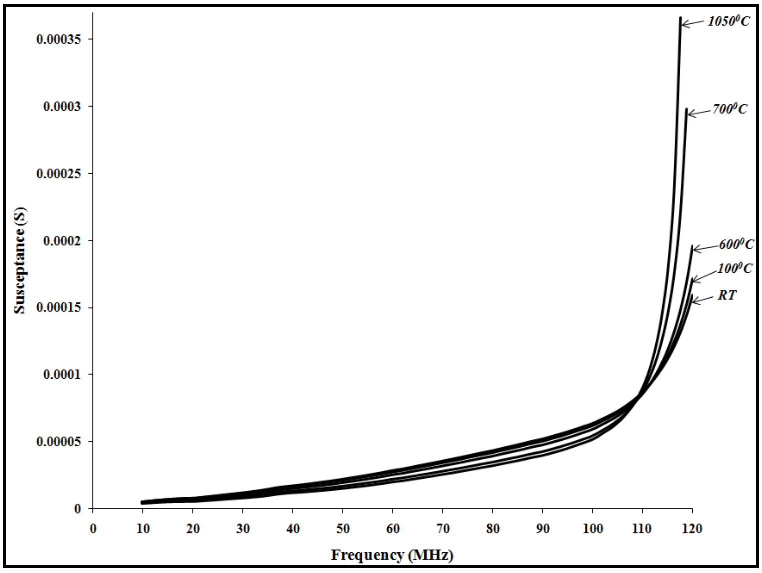

Fig. 3. Susceptance of muscovite ruby mica annealed at different temperatures.

The loss tangent (tanδ; also known as dielectric loss factor or dissipation factor) of a dielectric material (like mica) is a parameter that measures its inherent dissipation of electromagnetic energy. In a complex plane it refers to the angle between the resistive component of an electromagnetic field and its reactive component. It is a measure of loss-rate of power of electrical oscillations in a dissipative system. The loss factor represents the ratio of resistance to reactance of a parallel equivalent circuit of the material. Figure 5 shows tanδ as a function of frequency (10-120 MHz) at different annealing temperature (RT-1050 °C) for muscovite ruby mica. The dissipation factor decreases firstly up to ~19 MHz and then in the frequency range ~19-35 MHz, it increases linearly. From 35 MHz it decreases up to 38 MHz and then increases for higher frequency. At higher frequency the annealing temperature strongly affects the dissipation factor and the latter increases as the annealing temperature increases. In the temperature interval of 600 °C-700 °C, the dissipation factor increases abruptly similar as for other parameters. The value of tanδ shifts with frequencies with increasing temperature might be related with the dipole relaxation phenomenon. In lower frequency region more energy is received for electron exchange during any oxidation, thus the energy loss is high. In the high frequency region, a small energy is needed for electron transfer during the oxidation hence the energy loss is small.

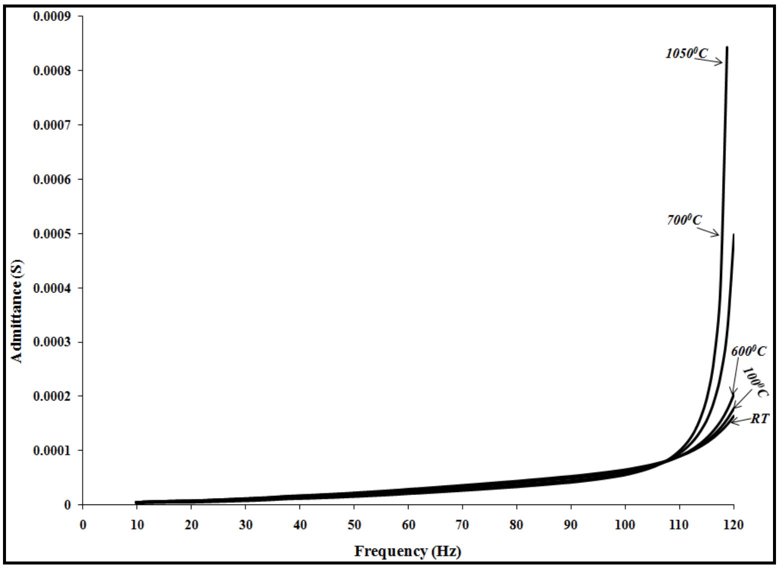

Fig. 4. Admittance of muscovite ruby mica annealed at different temperatures.

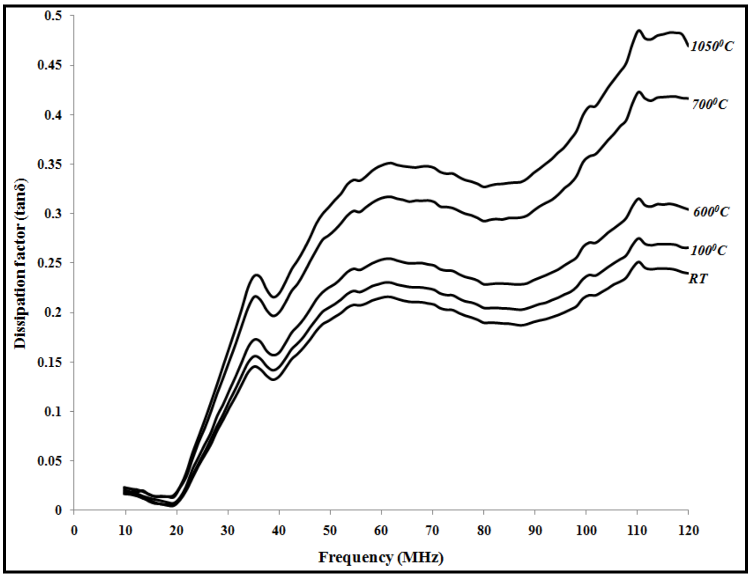

Fig. 5. Dissipation factor (tanδ) of muscovite ruby mica annealed at different temperatures.

Quality factor (also known as Q factor or storage factor) is a measure of the ability of a periodic system to store energy equal to 2π times the average energy stored divided by the energy dissipated per cycle. Higher the quality factor lower will be the electric loss for dielectrics. Figure 6 presents the Quality factor as a function of frequency at different annealing temperatures for muscovite mica. The pristine muscovite mica have high quality factor at frequency 19 MHz as compared to the rest of frequencies. As the annealing temperature increases from room temperature to 1050 ^{o}C, the quality factor decreases. There is large decrease in quality factor during the temperature interval 600-700 ^{o}C. The high temperature annealed mica shows approximately 72% low quality factor as compared to the unannealed mica. This reveals that thermal treatment strongly affects the quality factor of muscovite mica and increases its electric loss.

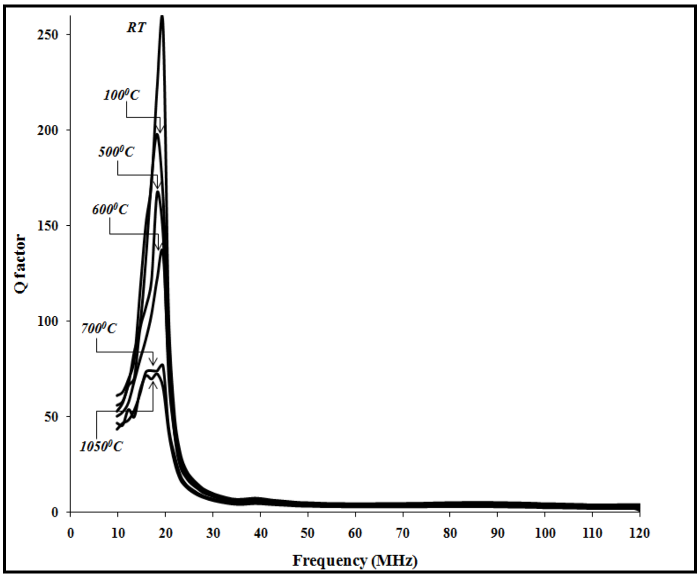

Fig. 6. Quality factor of muscovite ruby mica annealed at different temperatures.

Static capacitance in series and parallel-equivalent circuit mode of muscovite ruby mica as a function of frequency at different annealing temperature are shown in Figs. 7 and 8 respectively. During the low frequency region (< 105 MHz) the capacitance decreases with the annealing temperature. Firstly the static capacitance decreases as the frequency increases from 10-20 MHz and then increases up to frequency 105 MHz. At this frequency the static capacitances show approximately the same values for all the annealed samples. At higher frequency region (> 105 MHz) capacitance for annealed samples is high as compared to un-annealed mica and it increases as the annealing temperature increases.

The main effects of thermal treatment on muscovite mica are the dehydration and dehydroxylation on a wide range of temperature interval (app. 500-1100 ^{o}C) depending on the mineral structure and its constituents. The crystalline muscovite phase changes to anhydrous dehydroxylated phase i.e. hydrous mineral become transforms into anhydrous mineral. In the dehydrated phase, Al cation is in five fold coordination and modified unit cell parameters [19-22].

4. Conclusion

It is concluded that various electrical/dielectric characteristics of muscovite ruby mica are greatly affected by thermal treatment. The present paper reveals that the high temperature annealed mica shows approximately 72% low quality factor as compared to the unannealed mica. There exists a critical threshold frequency (~105-110 MHz) where the present mica shows the negligible thermal effect. It is strongly recommended that the electrical/dielectric characteristics of this type of dielectrics affected by the thermal treatment should be studied and analysed for better understanding and utilization of muscovite in various high temperature and frequency equipments.

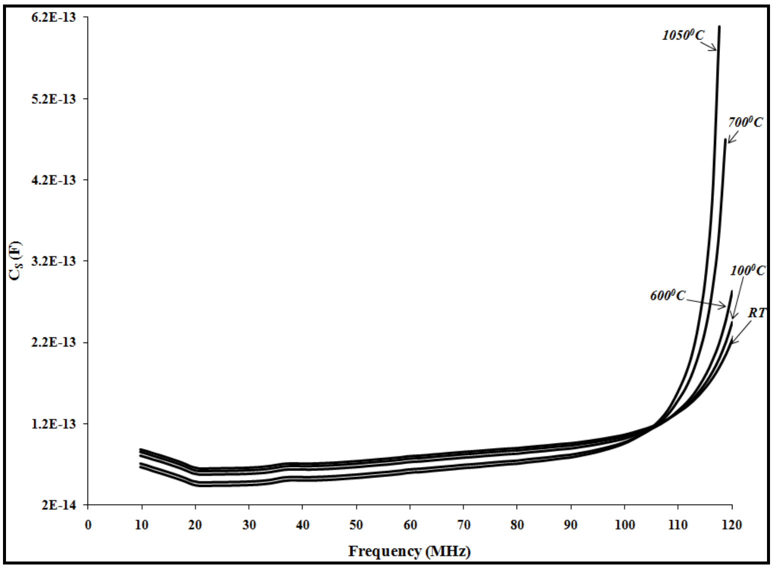

Fig. 7. Static capacitance in series-equivalent circuit mode of muscovite ruby mica annealed at different temperatures.

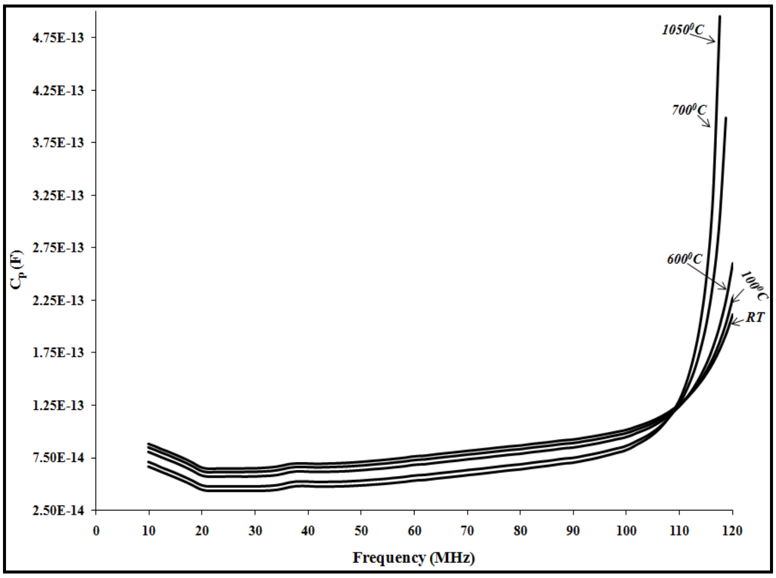

Fig. 8. Static capacitance in parallel-equivalent circuit mode of muscovite ruby mica annealed at different temperatures.

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