Ernst-Abbe-Hochschule Jena
University of Applied Sciences

MATERIALS FOR SENSORS AND ELECTRONICS

LAB REPORT:

FERROELECTRICITY - PERMITTIVITY

By:

Chakra Shree Harsha Aravilli Venkata,

Matrikel Nr: **651503**

Under the guidance of:

PROF. David Smykalla

Table of Contents

ABSTRACT 3
THEORY 4
PROCEDURE 5
OBSERVATIONS 6
Readings for Increasing Temperature 6
Readings for Decreasing Temperature 8
GRAPHS & DISCUSSIONS 9
PERMITTIVITY 9
INVERSE OF RELATIVE PERMITTIVITY 11
CONCLUSION 12

List of Graphs

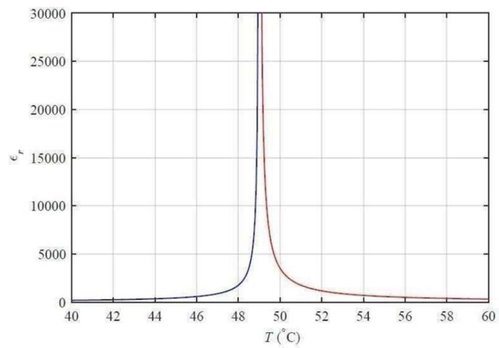
Graph 1: Theoretical Permittivity vs Temperature 4
Graph 2: Theoretical Inverse Relative Permittivity vs Temperature 4
Graph 3: Permittivity vs Temperature under Heating process 10
Graph 4: Permittivity vs Temperature under Cooling process 10
Graph 5: Inverse relative permittivity vs temperature under Heating process 11
Graph 6: Inverse relative permittivity vs temperature under cooling process 11

ABSTRACT

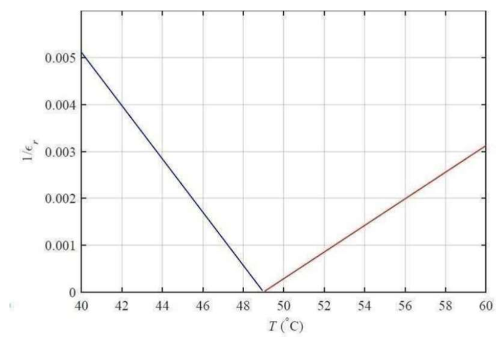
The dielectric constant or permittivity, of a material is an important feature in electricity and magnetism. It shows how well a material can store electrical energy. To find the dielectric constant of a solid, we measure the capacitance of a capacitor that has the material inside it. In this experiment, we will find the dielectric constant (e) of a TGS crystal. We'll see how it changes with temperature, starting from room temperature up to 75°C. We will do this at a frequency of about 2 kHz. The experiment consists of two parts. Increasing Temperature, we will slowly increase the temperature and measure the dielectric constant of the TGS crystal at different points. This will show us how the material behaves as it gets hotter. Decreasing Temperature, after reaching 75°C, we will let the crystal cool down and again measure the dielectric constant at different temperatures. This will help us see if there are any differences between heating and cooling. By doing this, we will learn how the TGS crystal's dielectric properties change with temperature.

THEORY

Landau theory is a theory that was introduced by Lev Landau to formulate a general theory of continuous phase transitions (Second order), it can be also used as a quantitative model for discontinuous transitions (First order). Landau's theory also states that the curie constant is different for heating and cooling phases.



Graph 1: Theoretical Permittivity vs Temperature



Graph 2: Theoretical Inverse Relative Permittivity vs Temperature

The dielectric constant (also called permittivity) ε of a dielectric material is measured mostly by determining the capacitance of the parallel plate capacitor containing the material. The capacity of a parallel plate capacitor is given by

$$C = \varepsilon . \frac{A}{d} \quad \text{with} \quad \varepsilon = \varepsilon_o * \varepsilon_r$$

where,

C – capacity of the parallel plate capacitor
A – area of the plates facing each other
d – distance of the two plates
ε – dielectric constant, also called permittivity
ε_o – dielectric constant or permittivity of the vacuum
ε_r – Relative dielectric constant or relative permittivity of a special material

For calculating the **Inverse Relative Permittivity**, we have

$$\frac{1}{\varepsilon_r} = \frac{\varepsilon_o}{\varepsilon}$$

where,

ε_r – Relative permittivity
ε_o – Permittivity of Free space (0.00885 pF/mm)
ε – Permittivity of TGS Crystal.

Here, we considered **Sample A** which have Thickness (d) as 1.01 mm and Area (A) 31.50 mm^2. So, the permittivity of this crystal can be given as shown below

$$\varepsilon = \frac{C * 1.01\ mm}{31.50\ mm^2}$$

here,

C – Capacitance is converted from Millivolts from the experimental setup 1mV=1pF

PROCEDURE

- Connect the two BNC connectors of the small aluminium sample box via BNC cables with the BNC connectors of the capacity measuring box. The two contacts of the sample relate to the middle wire. The outer shell of the BNC connectors is only used for shielding.
- Connect a digital handheld multimeter with the output connectors of the capacity measuring box (black and red connectors). Use at first the V-AC range of the multimeter.
- Switch the multimeter on. Now you should see on the multimeter a voltage that corresponds to the capacity of the sample. 1 mV corresponds to 1pF.
- Connect the heater inside of the aluminium sample box (black and red connector) with the current supply. In the beginning, the current supply is switched off.
- Connect the DIN female connector of the aluminium sample box with the DIN female connector of the temperature measuring box. Use the brown cable with the two DIN male connectors.
- Connect a digital multimeter with the output of the temperature measuring box (black and red connectors). Use the 20 V DC range of the multimeter.
- Switch the multimeter on. Now you should see on the multimeter a voltage that corresponds to the temperature of the sample. 0.1 V corresponds to 1 °C.
- Now begin with the measurement of the temperature dependence of the sample capacity. Switch the heating current on and measure the capacity in intervals of about 1 °C. The heating voltage should be not too high. Otherwise, you get temperature measuring errors. Between room temperature and 47 °C, you should use a temperature increasing velocity of about 1 °C/minute. As a recommended value use a heating voltage of about 5 V. In the region between 47 °C and about 51 °C (until you notice that the Curie temperature is passed) the heating velocity should be very slow. Try to use about **0.2 °C/minute** and measure in intervals of about 0.2 °C. If you have passed the Curie temperature you can increase the heating velocity again to about 1 °C/minute. Be careful! Do not exceed a sample temperature of 75 °C.

- After reaching 65 °C reduce the heating current and measure the sample capacity for falling temperature again in intervals of 1 °C. Try to use again a cooling velocity of 1 C/minute far away from the Curie temperature and **0.2 °C/minute between 51 °C and about 47 °C** until you have passed the Curie temperature. After passing the Curie temperature you can further decrease the heating current and increase the cooling velocity again to about 1 °C/minute.

OBSERVATIONS

There are two multi-meters in the apparatus of the experiment and one of them shows us the temperature in terms of voltage which is converted into °C by using the conversion formula of **0.1V = 1°C**. The other multi-meter shows us the capacity in volts which is converted by using the conversion rate of **1mV = 1pF**. The readings are taken for increasing temperature and decreasing temperature which are provided below.

Readings for Increasing Temperature

Temperature (°C)	Capacitance (pF)	Permittivity ε	Inverse Permittivity
22.2	26.7	0.856095238	0.010337635
23	26.1	0.836857143	0.010575282
24	29.5	0.945873016	0.009356436
25	30.3	0.97152381	0.009109401
26	31.1	0.997174603	0.008875076
27	32	1.026031746	0.008625464
28	33	1.058095238	0.008364086
29	34.2	1.096571429	0.00807061
30	35.5	1.138253968	0.007775066
31	37.9	1.215206349	0.007282714
32	40	1.282539683	0.006900371
33	42.2	1.353079365	0.006540636
34	44.6	1.430031746	0.006188674
35	47.2	1.513396825	0.005847772
36	49.9	1.599968254	0.00553136
37	53.5	1.715396825	0.005159156
38	57	1.827619048	0.004842366
39	60.8	1.949460317	0.004539718
40	63.3	2.029619048	0.004360424
41	67.8	2.173904762	0.004071016
42	73.5	2.356666667	0.003755304
43	80.5	2.581111111	0.003428756
44	91.8	2.943428571	0.003006698
45	110	3.526984127	0.002509226

46	136.6	4.379873016	0.002020607
47	182	5.835555556	0.001516565
47.2	215	6.893650794	0.00128379
47.4	236	7.566984127	0.001169554
47.6	274	8.785396825	0.001007353
47.8	332	10.64507937	0.00083137
48	423	13.56285714	0.000652517
48.2	596	19.10984127	0.000463112
48.4	1095	35.10952381	0.000252068
48.6	1827	58.58	0.000151075
48.8	1640	52.58412698	0.000168302
49	1311	42.0352381	0.000210538
49.2	991	31.77492063	0.000278522
49.4	850	27.25396825	0.000324723
49.6	710	22.76507937	0.000388753
49.8	608	19.49460317	0.000453972
50	522	16.73714286	0.000528764
50.2	459	14.71714286	0.00060134
50.4	416	13.3384127	0.000663497
50.6	377	12.08793651	0.000732135
50.8	346	11.09396825	0.000797731
51	320	10.26031746	0.000862546
51.2	296	9.490793651	0.000932483
51.4	276	8.84952381	0.001000054
51.6	259	8.304444444	0.001065694
51.8	244	7.823492063	0.001131208
52	227	7.278412698	0.001215924
53	180	5.771428571	0.001533416
54	144.3	4.626761905	0.001912785
55	122.7	3.934190476	0.00224951
56	107.2	3.437206349	0.002574765
57	95.2	3.052444444	0.002899316
58	85.6	2.744634921	0.003224473
59	78	2.500952381	0.003538652
60	71.2	2.282920635	0.003876613
61	65.7	2.106571429	0.004201139
62	61.4	1.968698413	0.004495356
63	57.5	1.843650794	0.004800258
64	54.1	1.734634921	0.005101938
65	51.1	1.638444444	0.005401465
66	48.3	1.548666667	0.005714593
67	46	1.474920635	0.006000323
68	43.8	1.404380952	0.006301709

69	41.8	1.340253968	0.006603226
70	40.1	1.285746032	0.006883163
71	38.5	1.234444444	0.007169217
72	37	1.186349206	0.007459861
73	35.7	1.144666667	0.007731508
74	34.4	1.102984127	0.008023688
75	33.3	1.067714286	0.008288734

Readings for Decreasing Temperature

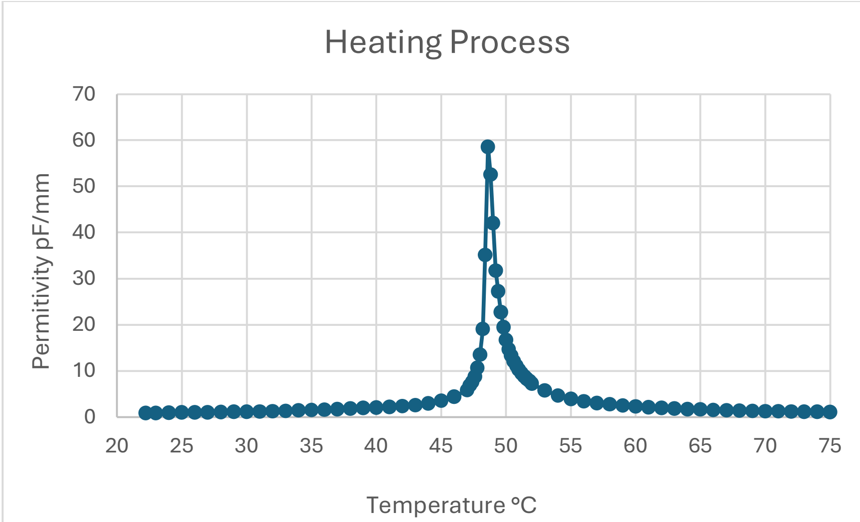
Temperature (°C)	Capacitance (pF)	Permittivity ε	Inverse Permittivity
75	33.3	1.067714286	0.008288734
74	34.5	1.106190476	0.00800043
73	36	1.154285714	0.007667079
72	37	1.186349206	0.007459861
71	38.5	1.234444444	0.007169217
70	40	1.282539683	0.006900371
69	41.8	1.340253968	0.006603226
68	43.8	1.404380952	0.006301709
67	46	1.474920635	0.006000323
66	48.3	1.548666667	0.005714593
65	51	1.635238095	0.005412056
64	54.2	1.73784127	0.005092525
63	57.5	1.843650794	0.004800258
62	61.5	1.971904762	0.004488046
61	66.2	2.122603175	0.004169409
60	71.5	2.292539683	0.003860348
59	78.3	2.510571429	0.003525094
58	85.6	2.744634921	0.003224473
57	95.2	3.052444444	0.002899316
56	107.2	3.437206349	0.002574765
55	122.8	3.937396825	0.002247678
54	143.8	4.610730159	0.001919436
53	174.4	5.591873016	0.001582654
52	230	7.374603175	0.001200065
51.8	242	7.759365079	0.001140557
51.6	260	8.336507937	0.001061596
51.4	274	8.785396825	0.001007353
51.2	296	9.490793651	0.000932483
51	318	10.19619048	0.000867971
50.8	346	11.09396825	0.000797731
50.6	377	12.08793651	0.000732135
50.4	418	13.40253968	0.000660323
50.2	470	15.06984127	0.000587266
50	537	17.21809524	0.000513994

49.8	632	20.26412698	0.000436732
49.6	760	24.36825397	0.000363177
49.4	970	31.1015873	0.000284551
49.2	1332	42.70857143	0.000207218
49	2590	83.04444444	0.000106569
48.8	3520	112.8634921	7.84133E-05
48.6	4112	131.8450794	6.71242E-05
48.4	3400	109.015873	8.11808E-05
48.2	2860	91.7015873	9.65087E-05
48	2430	77.91428571	0.000113586
47.8	2100	67.33333333	0.000131436
47.6	1849	59.28539683	0.000149278
47.4	1674	53.67428571	0.000164883
47.2	1559	49.98698413	0.000177046
47	1452	46.55619048	0.000190093
46	1119	35.87904762	0.000246662
45	915	29.33809524	0.000301656
44	757	24.27206349	0.000364617
43	636	20.39238095	0.000433986
42	553	17.73111111	0.000499123
41	480	15.39047619	0.000575031
40	424	13.59492063	0.000650978
39	376	12.05587302	0.000734082
38	336	10.77333333	0.000821473
37	301	9.651111111	0.000916993
36	272	8.721269841	0.00101476
35	247	7.91968254	0.001117469
34	225	7.214285714	0.001226733
33	205	6.573015873	0.001346414
32	181.8	5.829142857	0.001518234
31	166.4	5.335365079	0.001658743
30	153.5	4.921746032	0.001798142
29	142.4	4.56584127	0.001938307
28	130.2	4.174666667	0.00211993

GRAPHS & DISCUSSIONS

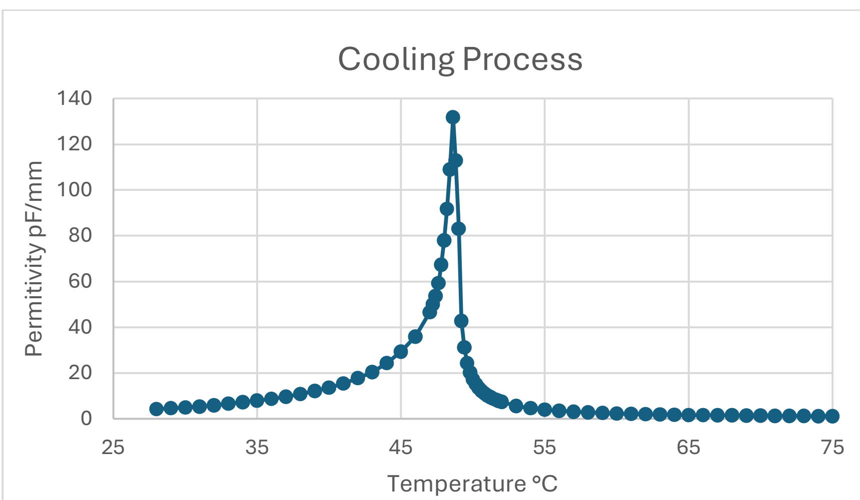
PERMITTIVITY

The graphical representation shows a change in permittivity concerning increasing Temperature. Here from the graph, it is observed that at **48.6ºC** we got a highest permittivity and the approximate value of this is **58.58 pF/mm**. Similarly, while decreasing the temperature of the sample to **48.6ºC** we got a peak permittivity of **131.8451 pF/mm**. The graphs for the cycles are shown below.



Graph 3: Permittivity vs Temperature under Heating process

From Graph 3, we can observe that the permittivity of the sample remains almost constant with very low increase in values at lower temperatures from 22.2°C till 45°C. But we see there is a Sudden peak rise in the permittivity level from 45°C till temperature 48.6°C where the highest permittivity (58.58 pF/mm) is seen while Heating.

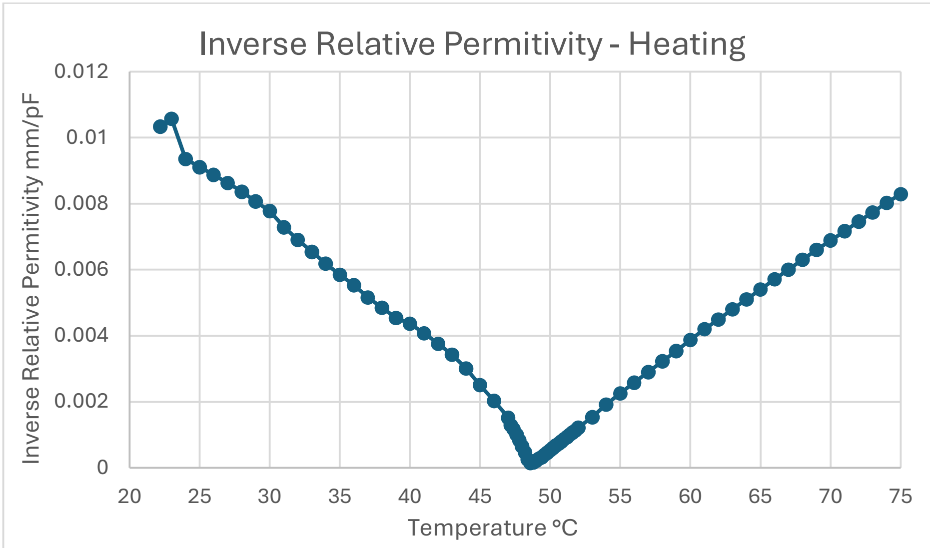


Graph 4: Permittivity vs Temperature under Cooling process

From Graph 4, we can observe the similar process while cooling from 75°C to 53°C as in Heating process. After reaching the temperatures less than 53°C, the permittivity of the sample gained rapid increase to the peak of 131.8451 pF/mm (2.5 times compared to Heating) at 48.6°C. Later, it attained gradual decrease.

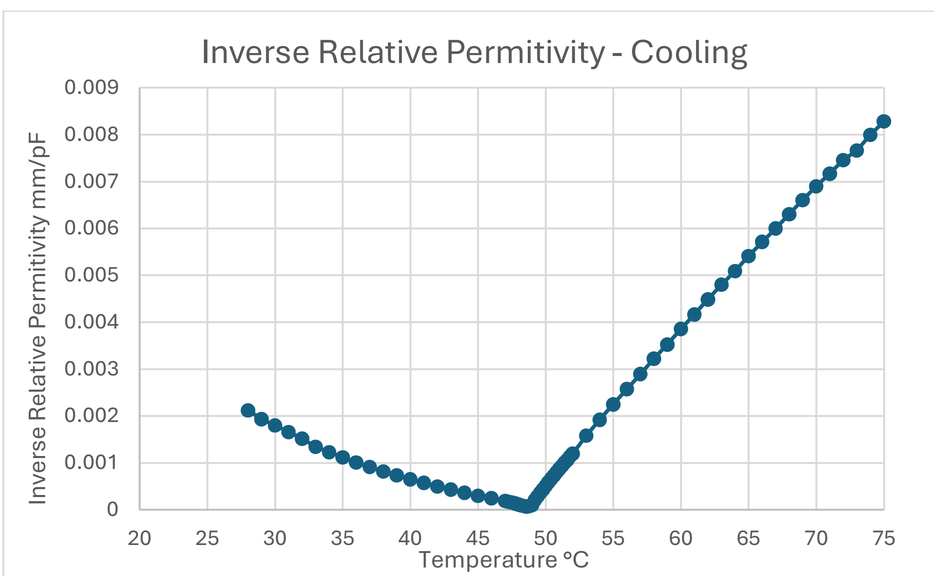
When compared with Theoretical values by Curie-Weiss law, at 49°C the material converts its properties from Ferroelectric to Paraelectric.

INVERSE OF RELATIVE PERMITTIVITY



Graph 5: Inverse relative permittivity vs temperature under Heating process

From Graph 5, on heating, the value for inverse relative permittivity decreases till curie temperature and it starts increasing gradually after curie temperature.



Graph 6: Inverse relative permittivity vs temperature under cooling process

From Graph 6, while cooling, we can see the Relative permittivity values at lower temperatures (less than Curie temperature) are less when compared with Heating.

CONCLUSION

According to Landau theory and Curie-Weiss law, a material acts as a ferroelectric material when the temperature is less than the curie temperature and as a para-electric material when the temperature is greater than the curie temperature. In the inverse relative permittivity graphs for both heating and cooling, we observe that the process of TGS crystal changing from ferroelectric to para-electric substance takes place continuously without breakage and with no loss of energy. Therefore, we can conclude that the transition which we see here is a **Second-order transition.** By comparing both the Theoretical and Practical graphs we can see that the slope of the curve in inverse relative permittivity almost reaches zero at curie temperature.

In this experiment, we obtained **Curie Temperature (T_c)** under Heating and Cooling processes at **48.6°C** and we know the theoretical value of T_c for TGS crystal is 49°C.