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Customized AC susceptibility set up for above room temperature measurements

Abstract

Magnetic susceptibility measurements are important for magnetically charactering the materials. Temperature dependent AC susceptibility measurements are key to understand the phase transition of several advanced materials such as multiferroics, High Tc Superconductors, colossal magnetoresistance materials etc. The commercially available susceptometers are complex as well as expensive. In the present report we have demonstrated AC susceptometer by employing the concepts of phase sensitive detection using a Lock-in amplifier. A setup having a primary coil and pair of oppositely wounded secondary coils were connected to Lock-in amplifier for phase locked voltage detection from secondary coils. For high temperature AC susceptibility measurement, heater with Nichrome as heating element was placed around the secondary coils. Calibration and measurements of AC susceptometer will be demonstrated in the present report.

1. Introduction

1.1. Magnetism

When the atomic dipoles are subjected to external magnetic field, they experienced a torque which tends them to align their magnetic moments in the direction of magnetic field. The magnetic moment per unit volume along the direction of magnetic field inside a solid is called magnetization and is denoted by M. The effect of magnetic field can be expressed as some relation like:

$$\mathbf{B} = \boldsymbol{\mu}_0(\mathbf{H} + \mathbf{M}) \quad \textbf{(1)}$$

Where, B is magnetic flux density or magnetic induction and is the measure of magnetic lines of force passing per unit area, measured in tesla (T) in SI and Gauss in CGS. H is the applied magnetic field measured in A/m. M is the magnetization measured in A/m. μ_0 is the magnetic permeability of free space measured in Tm/A.

1.2. Magnetic Susceptibility

Magnetic Susceptibility is a measure of how “Magnetic” a material is and represents the response of the material to the applied field hence is defined as the magnetization produced per unit applied Magnetic field.

$$\chi = M/H \quad (2)$$

Where, χ is called magnetic susceptibility of material. For isotropic medium χ is a scalar quantity. Generally, it is a dimensionless quantity. The magnetic susceptibility is classified as, ac magnetic susceptibility and dc magnetic susceptibility. In ac susceptibility, we deal with varying magnetic field. AC susceptibility is a slope of magnetization curve (M versus H curve).

$$\chi_{ac} = \frac{dM}{dH} \quad (3)$$

In DC susceptibility, we deal with constant magnetic field.

$$\chi_{dc} = M/H_{dc} \quad (4)$$

The ac technique detects the change in magnetization that leads to dM/dH in the limit of small ac field, and therefore sometimes referred to as a differential susceptibility. This is the fundamental difference between the ac and dc measurements techniques. AC susceptibility has a great application in different fields, like spin glass, supermagnetism, superconductivity etc.

2. Instrumentation

2.1. Susceptometer

The susceptometer used in our project is used to measure susceptibility variation for the materials having high phase transition temperature. So, it was very important to use the

Fig :(1) cross-sectional diagram of susceptometer

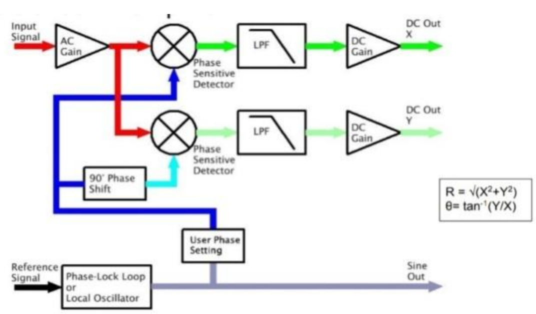
material on which winding Should be done has the properties like Non-Magnetic, electric insulator, good thermal conductor, minimum thermal expansion and having high melting point.Here in our susceptometer quartz tube is used as a material on which winding is done as it is electrically and thermally stable and has a very high melting point(~1700°C). Also, dual coated copper wire was used for winding as it can withstand a high temperature (200°C). In order to provide proper insulation mica tape is wounded on copper winding. The primary coil, secondary coils, heater and sample holder are kept coaxially with each other. In secondary coils opposite winding is done so that the magnetic flux due to both the detection coils cancels each other and the sample can experience only the flux generated by primary coil. Cross sectional diagram of susceptometer is as given figure.1. Resistance of primary coil is **13.4 Ω,** resistance of secondary coil is **55 Ω** and resistance of heater is **208 Ω**.

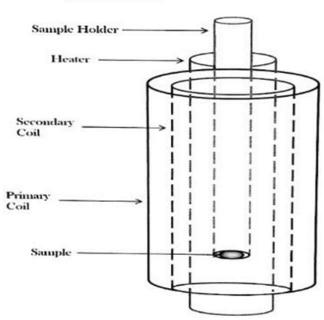
2.2. Lock in Amplifier

Lock-in amplifier is used to detect and measure very small ac signals- all the way down to a few nanovolts. Accurate measurement may be made even when the small signal is obscured by noise sources many thousands of times larger. Lock-in amplifier use a technique known as **phase sensitive detection** to signal out the component at a specific reference frequency and phase. Noise signals at frequencies other than the reference frequency are rejected and do not affect the measurement. The Lock-in consists of **five** stages.

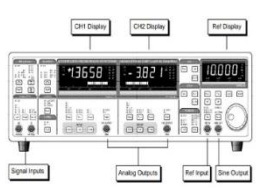
Figure:2 (a) Block diagram of Lock-in amplifier

(1) AC amplifier
(2) Voltage controlled oscillator (VCO)
(3) Multiplier {phase sensitive detector (PSD)}
(4) Low pass filter





(5) DC amplifier
The block diagram and photograph of Lock-in amplifier is shown in figure.2.



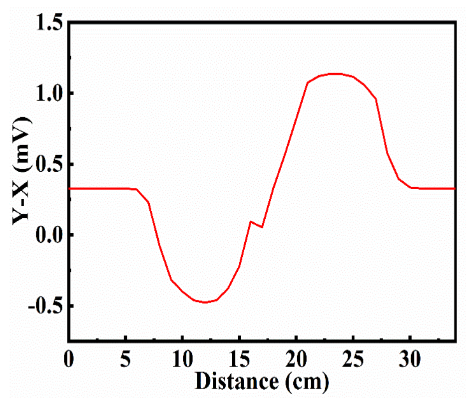
Fugure:2(b) Lock-in amplifier

3. Calibration and Data Acquisition

3.1. Calibration of the coil arrangement

Calibration of the set up proves that the winding of the secondary coils is done correctly. Here a ferromagnetic material was put inside the sample holder. Sinusoidal input voltage having frequency 165kHz and amplitude 1 $V_{p\text{-}p}$ was given to the primary coil and the output was drawn from secondary coils was applied to the **X-Channel** of Lock-in amplifier. When sample was inserted in the coils, due to the change in position of sample the flux gets generated in the secondary coils measured in the Lock-in amplifier. Gained output voltages were of the order of millivolts. Experimental set up and graph of the readings of distance of ferromagnetic material versus difference of X-Channel and Y-Channel shown in figure (3) and figure (4) respectively.

Fig: (3) Experimental set up for calibration of Susceptometer



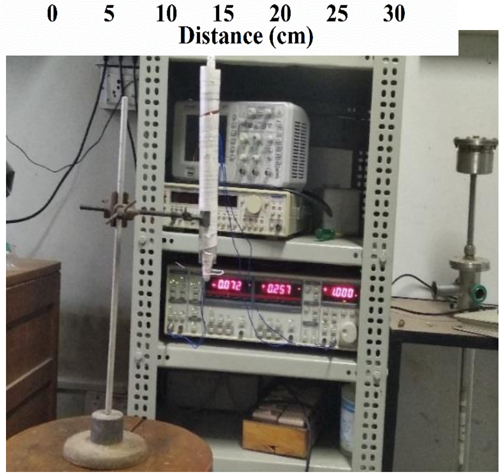


Fig: (4) Graph of voltage difference between X-Channel and Y-Channel versus distance

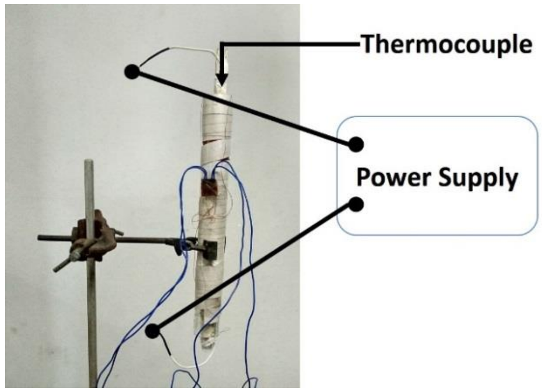
3.2. Calibration for high temperature

To find out the capability of sustaining a temperature in heater the terminals of wires are connected with variac. Than by increasing applied voltage and hence current accordance it and hence tempraof the heater will increase as per the Joule's heating lae. Now by inserting K type thermocouple we had measured the temperature. We have safely gained 182° C Temperature at 76V applied voltage. Schematic of high temperature susceptibility setup is shown in figure (5).

Fig:(5) schematic of high temperature susceptibility setup

4. Summary and Future scope

Low cost sample holder for low frequency AC susceptibility is fabricated and calibrated for high



temperature measurements. By using this set up we can measure high temperature and low temperature susceptibility of various ferrites materials and ferromagnetic materials. We plan to use the set up for collecting the AC susceptibility data on various ferromagnetic, ferrimagnetic and metals.

References

I. Charles Kittel, Introduction to Solid State Physics, Johns Wiley &sons 1995
II. S.O Pillai, Solid State Physics, New Age International 8th Edition (2008)
III. NPTEL: Metallurgy and material science –Electronics
IV. User Manual Lock-In Amplifier SR830, Stanford Research Systems, USA
V. MSc Thesis, Debjani Banerjee, NIT Rourkela (2011)
VI. AC Susceptibility Nikolo, American Journal of Physics 63(1), January 1995
VII. AC magnetic measurements, Dinesh Martien, Quantum Design (2010)
VIII. (XI) AC Susceptibility, Sue Kilcoyne, IOP magnetism meeting, London, October 2004

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