Resistivity measurement using four probe apparatus for VO_2

Saravanan Rajendran

October 22, 2020

1 Introduction

Vanadium oxide is an inorganic compound that undergoes structural phase transitions at different temperatures. The resistivity measurements of the compound becomes an interest as it undergoes different conducting phases (Metal- Insulator transitions) and also as being an Mott insulator. The objective is to measure resistivity of VO_2 at different temperatures using four probe apparatus.

2 Instruments description

2.1 Four probe apparatus

A four probe apparatus having four leads and a current source is used for measuring the resistivity of the sample. It has two inner leads connected to a high impedance voltmeter to measure the potential drop across the sample for a known current supplied through the battery. In two probes method, the potential drop across the sample is measured using the same probes that supply the current. Hence, the contact resistance appears as an error in voltage measurement. In four probe apparatus this is skipped by having inner probes to measure the potential drop which discards the contact resistance made buy other two probes. The probe is made into contact with the sample using silver paste.

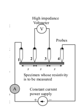

Figure 1: Four probe apparatus

2.2 Nano voltmeter

A nanovoltmeter which is highly sensible to measure nanovolts is used to measure the resistivity of the sample. It has high measurement speed according to the step size of the temperature and has better noise performance.

Figure 2: keithley nanovoltmeter

2.3 Rotary pump

A rotary pump is used for evacuating the chamber in which the sample is heated. It has two gears connected in which one gear is driven through motor. The air is discharged from the outlet because of the rotation of the gears or rotors and the atmospheric pressure sucks the fluid from the inlet which is connected to the chamber. The pump can achieve suction upto 10^{-6} mbar.

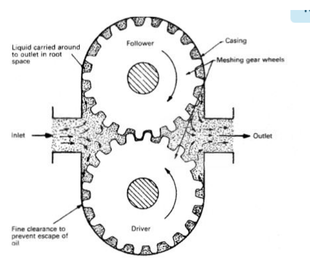

Figure 3: Rotary pump

3 Theory

According to ohm's law, at constant temperature, steady current (I) flowing through a conductor makes a proportional potential drop (V) across the semi-conductor.

$$V = IR$$

Where 'R' is the resistance of the conductor. It can be written as,

$$J = \sigma E$$

Where sigma is conductivity tensor and as it is constant throughout the sample tensor order reduces to 1. The conductivity of a material depends on the carrier concentration and the mobility of the carrier.

$$\sigma = n_i q \mu$$

As the temperature increases the carriers move to conduction band and the carrier concentration is obtained by density of states as,

$$\sigma = Ce^{-\frac{E_g}{2kT}}$$

and

$$\rho = \frac{1}{\sigma} = Ae^{\frac{E_g}{2kT}}$$

The resistivity of the sample changes as the change in temperature.

4 Procedure

The sample is heated using a heater and a insulator (mica) is kept between to avoid electrical measurements from the heater. The sample is made contacts with the four probes by using silver paste. The dimension of the contact (silver paste) must be greater than that of the separation between the probes. The inner two probes is sent to voltmeter and the outer probes is connected to the battery. The pump is driven to evacuate the chamber as the sample is not contaminated during heating. The heater with four probe apparatus is sent inside the evacuating chamber and the voltages are measured using Nanovoltmeter (Keithley). The readings are taken for various temperatures by the computer interfaced with the voltmeter.

5 Results and Analysis

- The resistivity of the sample decreases with increasing temperature which is an characteristic of the semiconductor. Hence, VO_2 is an semi metallic compound.
- Vanadium oxide undergoes a structural transition at 340 K from monoclinic to rutile. Hence, at 340 K drastic change of resistivity is seen.

References

[1] Charles Kittel. *Introduction to solid state*. John Wiley & Sons, 1966.

[2] AL Pergament, GB Stefanovich, NA Kuldin, and AA Velichko. On the problem of metal-insulator transitions in vanadium oxides. *ISRN Condensed Matter Physics*, 2013, 2013.

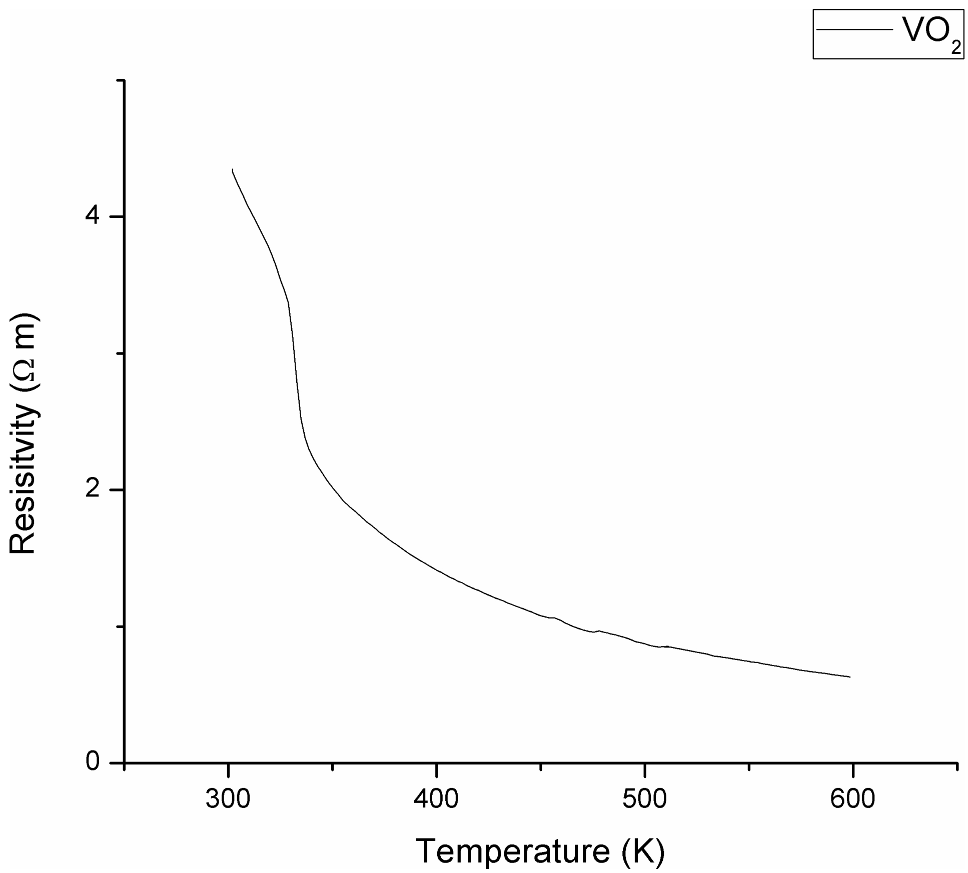

Figure 4: Temperature dependent resistivity of VO_2