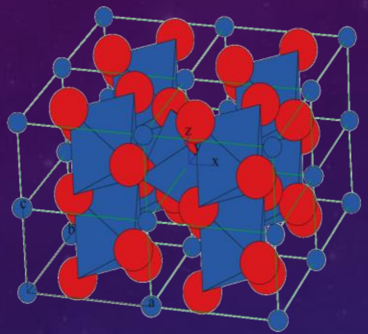
HALL EFFECT ON VANADIUM OXIDES THIN FILMS



Speaker: Mileidy Varela

Graduate Seminar I
Physics Department

There are some metal oxides that show a metal-insulator transition (MIT). Among those are vanadium oxides. Around a certain critical temperature (VO_2 at T_{MIT} = 67 ˚C) they present a phase transition accompanied by changes according to their stoichiometry in their structure, electrical, magnetic and optical behavior. Vanadium oxides, thanks to their good IR (infrared) absorption characteristics and manufacturing compatibility, can be used in information screens, variable reflector mirrors, smart windows, energy emission surfaces, memory devices and temperature sensors.

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Hall Effect on Vanadium Oxides Thin Films

MILEIDY VARELA

OCT-30-2018

PhD. Armando Rúa

Advisor

Outline

- Hall Effect
  - Van der Pauw Technique
- Vanadium Oxides Films
  - Sputtering Reactive DC
- Previews Studies
- My proposal
- Conclusion

Hall Effect

https://www.youtube.com/watch?v=pEjzUqLAJAM

- It is the voltage difference or electric field (named the **Hall** voltage) across an electrical conductor, transverse to an electric current in the conductor due to an applied magnetic field which is perpendicular to the current [1].

Fig 1. Hall Effect Diagram

[1] *Edwin Hall (1879). "On a New Action of the Magnet on Electric Currents". American Journal of Mathematics.* **2** *(3): 287–92.* doi:10.2307/2369245.

Hall Effect

- **Lorentz Force:** $\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$

$$\vec{F}_B = q\vec{v}_d \times \vec{B}$$

$$qv_dB = qE_H \qquad E_H = v_dB$$

$$\text{area } A = td \qquad v_d = \frac{I}{nqA}$$

$$\Delta V_H = E_H d = v_d B d$$

$$\Delta V_H = \frac{IBd}{nqA} = \frac{R_H IB}{t} \qquad \textbf{(1)}$$

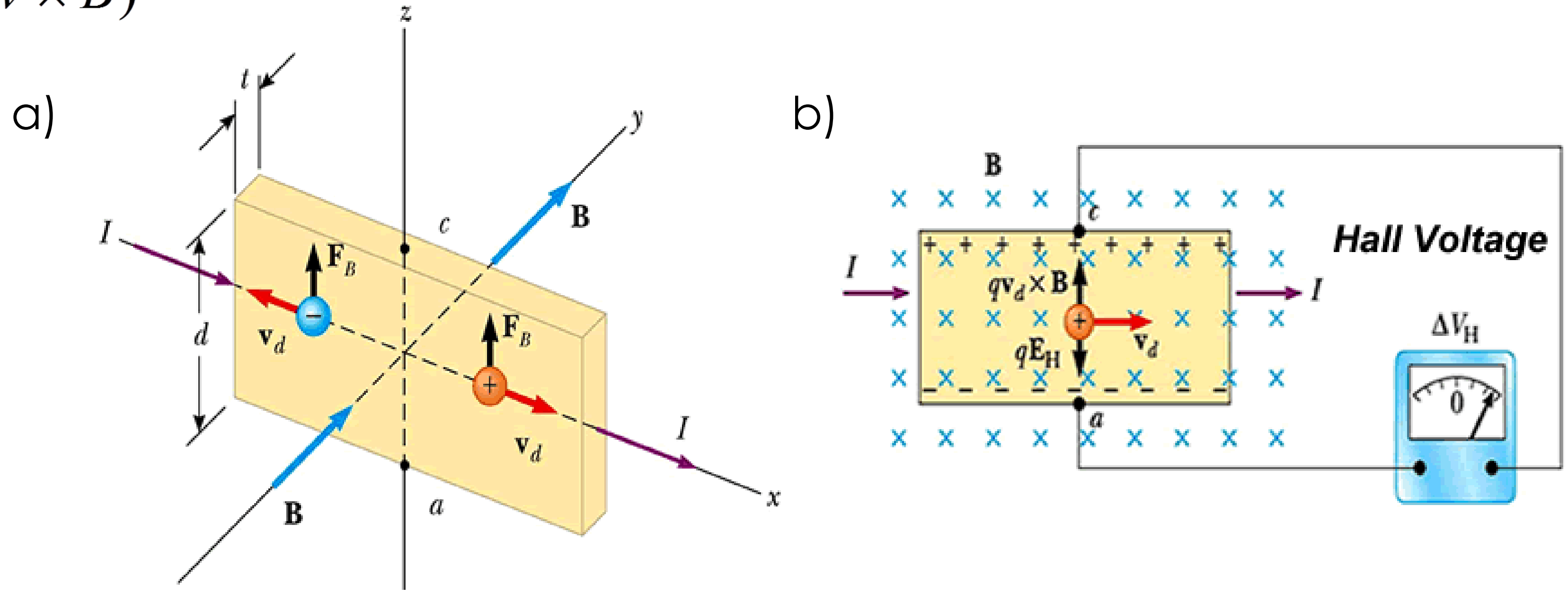


Fig 2. Representations of a) Lorentz Force and b) Hall Voltage

Hall Effect

- This transverse voltage is the Hall voltage V_H and its magnitude is equal to.

$$V_H = IB/qnd \qquad \textbf{(2)}$$

- The sheet density n_s of charge carriers in semiconductors ($n_s = nd$) as

$$n_s = IB/q|V_H| \qquad \textbf{(3)}$$

- Since sheet resistance involves both sheet density and mobility, the Hall mobility is

$$\mu = |V_H|/R_S IB = 1/(qn_S R_S) \qquad \textbf{(4)}$$

Van der Pauw Technique

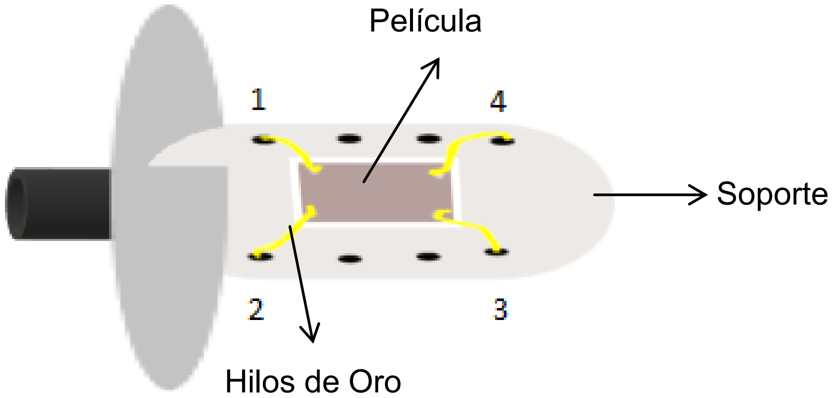


Fig 3. Van der Pauw experimental setup.

1. Have a uniform and flat thickness.
2. It must be homogeneous and isotropic.
3. It must not contain holes in it.
4. The four points should be located at the edges.
5. The area of this must be larger (an order of magnitude) than the contact area of any point.

Van der Pauw Technique

- It uses an arbitrarily shaped, thin-plate sample containing four very small ohmic contacts placed on the periphery (preferably in the corners) of the plate.

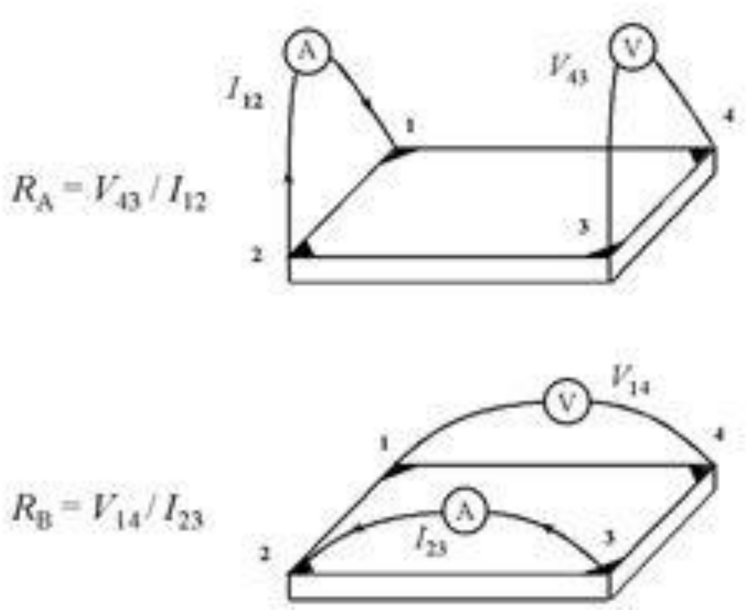


Fig 4. Resistance Measurements.

The Van der Pauw equation associate two characteristic resistances R_A and R_B, associated with R_s:

$$e^{\left(-\frac{\pi R_A}{R_s}\right)} + e^{\left(-\frac{\pi R_B}{R_s}\right)} = 1 \qquad \textbf{(5)}$$

R_A and R_B are calculated by means of the following expressions:

$$R_A = V_{43}/I_{12} \text{ and } R_B = V_{14}/I_{23}. \qquad \textbf{(6)}$$

Van der Pauw Technique – Hall Effect

- The objective of the Hall measurement in the van der Pauw technique is to determine the sheet carrier density n_s by measuring the Hall voltage V_H.

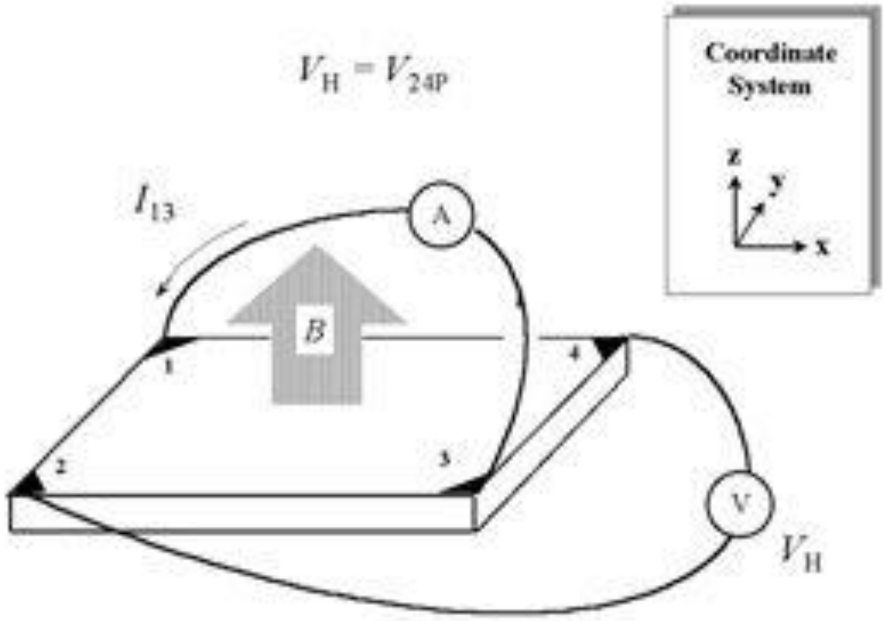


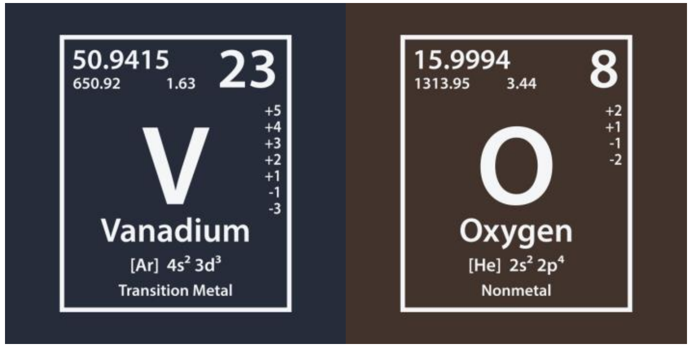
Fig 4. V_H Measurements.

To measure the Hall voltage V_H, a current *I* is forced through the opposing pair of contacts 1 and 3 and the Hall voltage is measured across the remaining pair of contacts 2 and 4.

$$V_H = V_{24} \qquad \textbf{(7)}$$

Vanadium Oxides Thin Films*

- Vanadium oxides is among them in which a certain critical temperature present a metal-insulator phase transition accompanied by changes, according to their stoichiometry, in their structure and in their electrical, magnetic and optical behavior, becoming more attractive when they are studied.



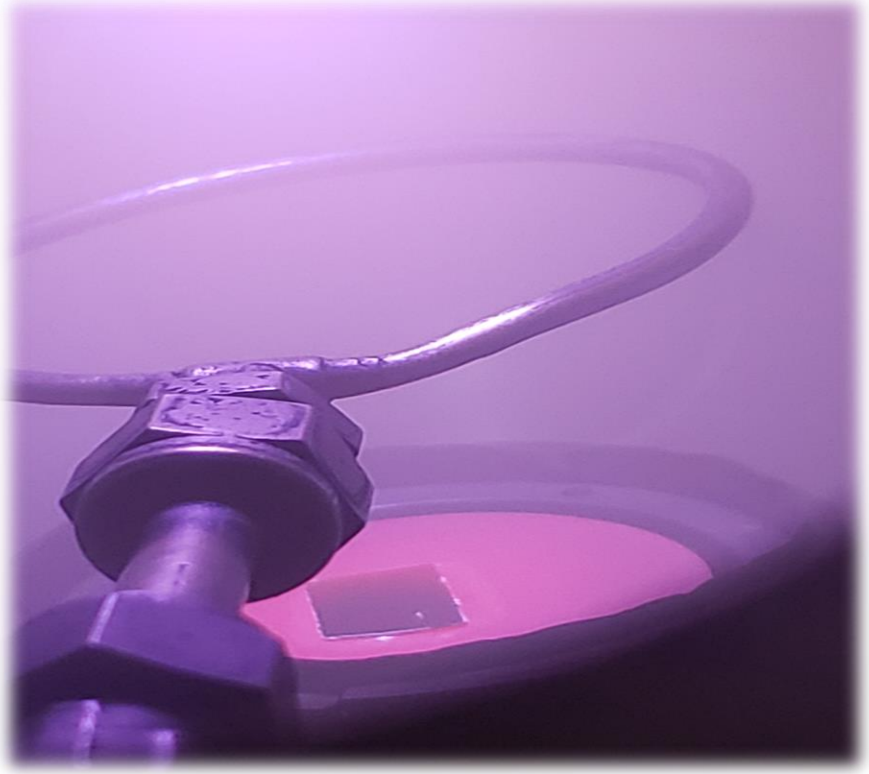


Fig 5. Deposition Sputtering for Vanadium Oxides.

*A thin film is a layer of material ranging from fractions of a nanometer (monolayer) to several micrometers in thickness.

Vanadium Oxides Thin Films - Applications

- The vanadium oxides can be used in:

  - ✓ Information screens.
  - ✓ Variable reflectivity mirrors.
  - ✓ *Smart windows.*
  - ✓ Variable emittance surfaces [2,3].
  - ✓ Memory devices.
  - ✓ Thermometers.

Fig 6. Smart Windows.

thanks to their good IR (infrared) absorption characteristics and manufacturing compatibility.

Vanadium Oxides Thin Films - Applications

- *Variable reflectivity mirrors*: They all switch from a metallic shiny state to an insulating transparent state.

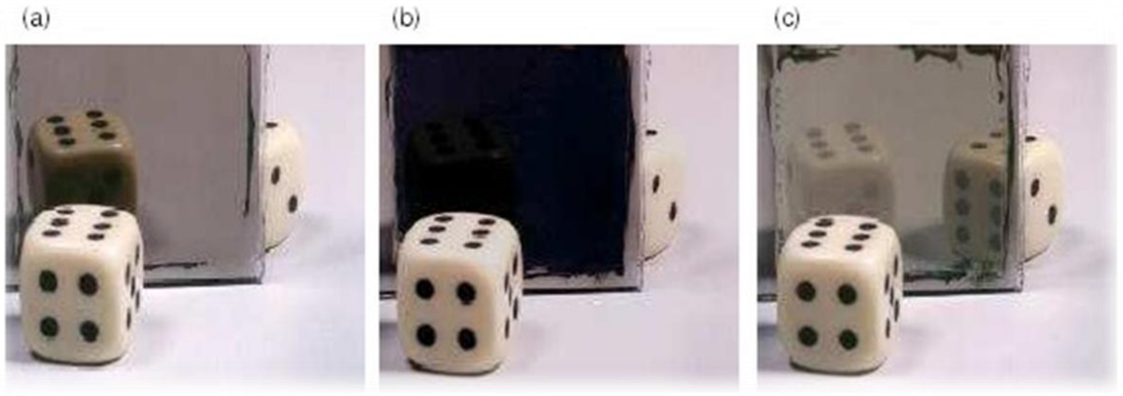


Fig 7. Variable reflectivity mirrors example.

Vanadium Oxides Films

Vanadium-oxygen system could be around 14 different types of oxides formed from the oxidation states +2, +3, +4 and +5.

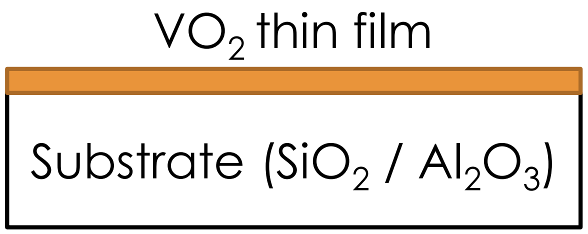
Wadsley phase

$V_{2n}O_{5n-2}$

where n values are between 1, 2 and 3

- Vanadium Dioxide (VO_2)

T_{MIT} ~ 340 K



Magnéli phase

V_nO_{2n-1}

where n values are between 3, 4, 5… 9

- vanadium dioxide (V_4O_7)

T_{MIT} ~ 250 K T_{Neel} ~ 40 K

Magnetron Sputtering Reactive DC

- Sputtering refers to a method of physical vapor.
- The Sputtering system can use different types of power known as DC, pulsed DC and RF.
- In the DC reactive Sputtering magnetron the created plasma is magnetically confined near the surface of the substrate.

Fig 8. Sputtering system*.

It was design in the Universidad de Puerto Rico-Mayaguez by the professor Felix Fernandez.

Magnetron Reactive Sputtering DC

- The positively charged ions in the plasma are accelerated [4] by an electric field, and the target atoms are expelled or "pulverized" and then deposited on a substrate.

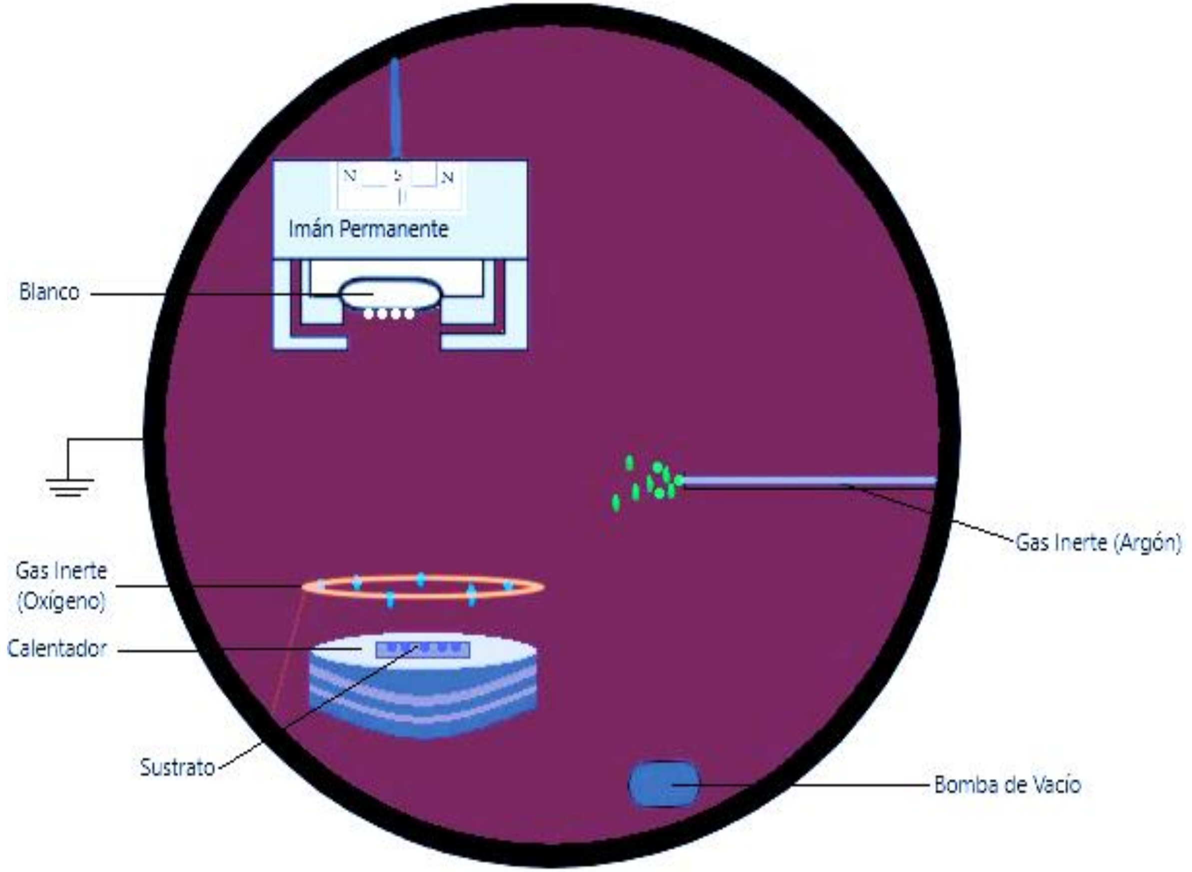
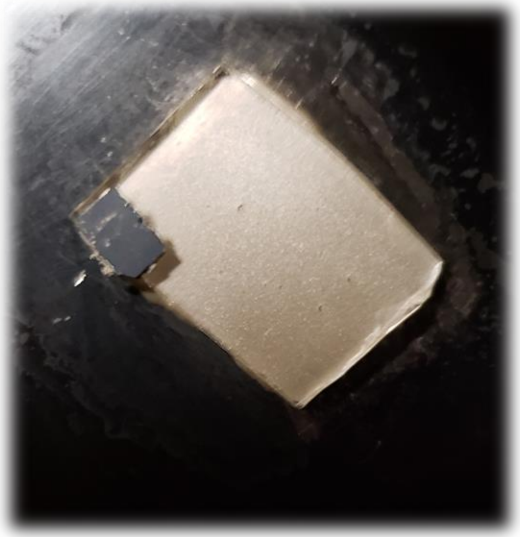


Fig 9. Sputtering diagram.

Magnetron Sputtering Reactive DC

a)



b)

c)

Fig 10. Sputtering Process. a) Substrate in the heater . b) Pre-sputtering time. c) Sputtering time

Magnetron Sputtering Reactive DC

Oxidation States	+5	+4	+3	+2
Oxides	V_2O_5	VO_2	V_2O_3	VO

a)

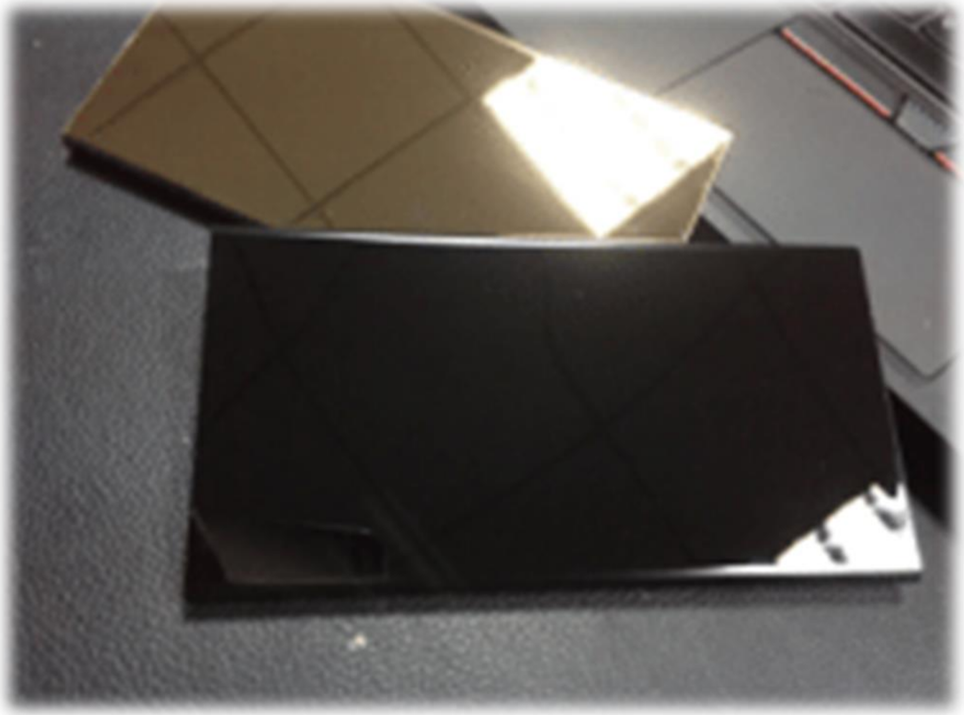


Fig 11. Thin Films Results.

Previews Studies

- *Hensler* et. al [5]:

Carrier charge: (negative sign)
Electrons.

Sample 2:
V_H = 0.13 cm²/V-sec a 300 °K

Sample 6:
V_H = 0.113 cm²/V-sec a 363 °K

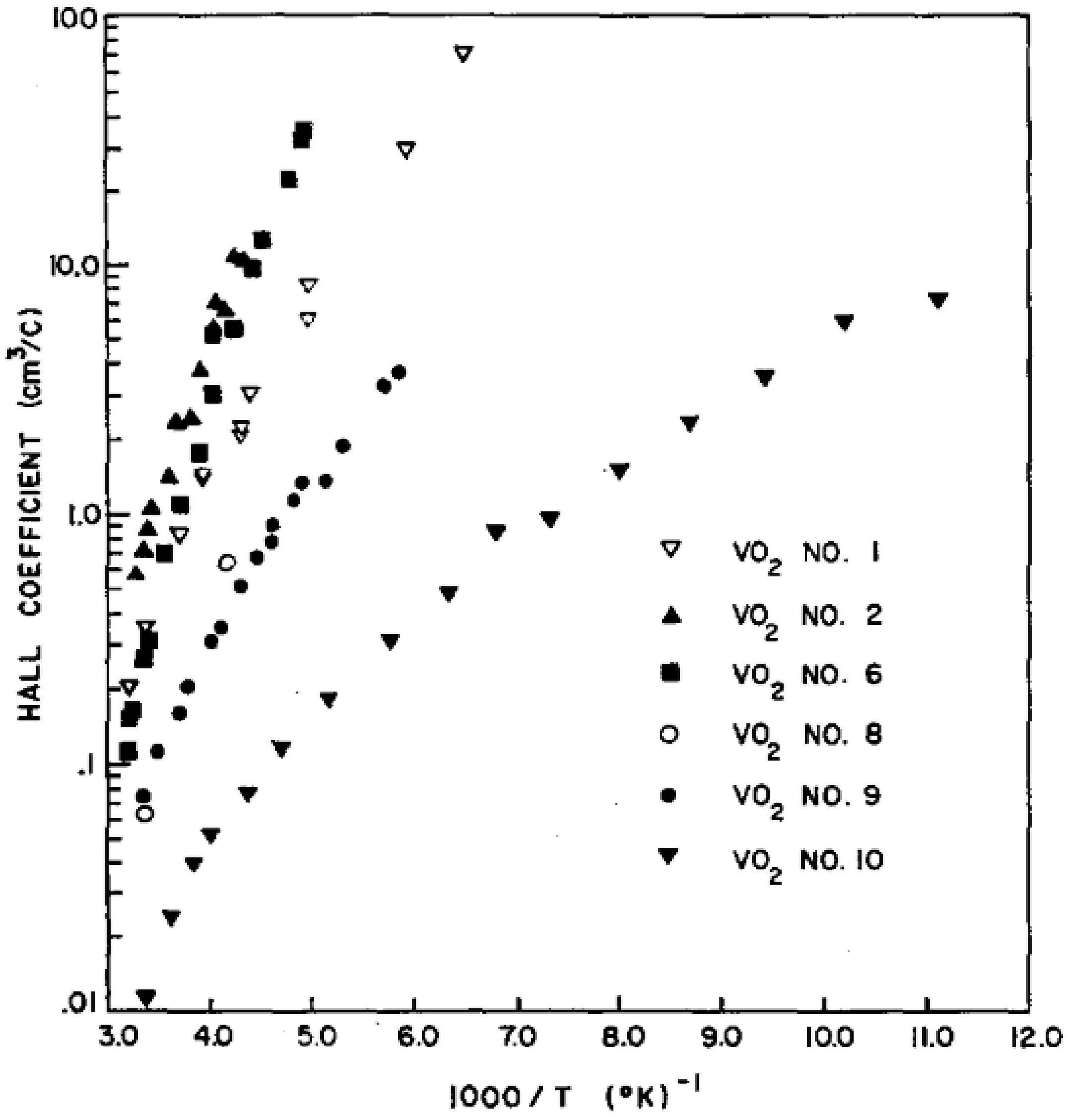


Fig 12. Hall coefficient vs reciprocal temperature substrate material.

Previews Studies

- *Ruzmetov et. al* [6]:

Carrier charge: (negative sign) Electrons.

V_H = 1.1 x 10^{19} cm^{-3} a 64 °C

hasta 1.7 x 10^{23} cm^{-3} a 75 °C.

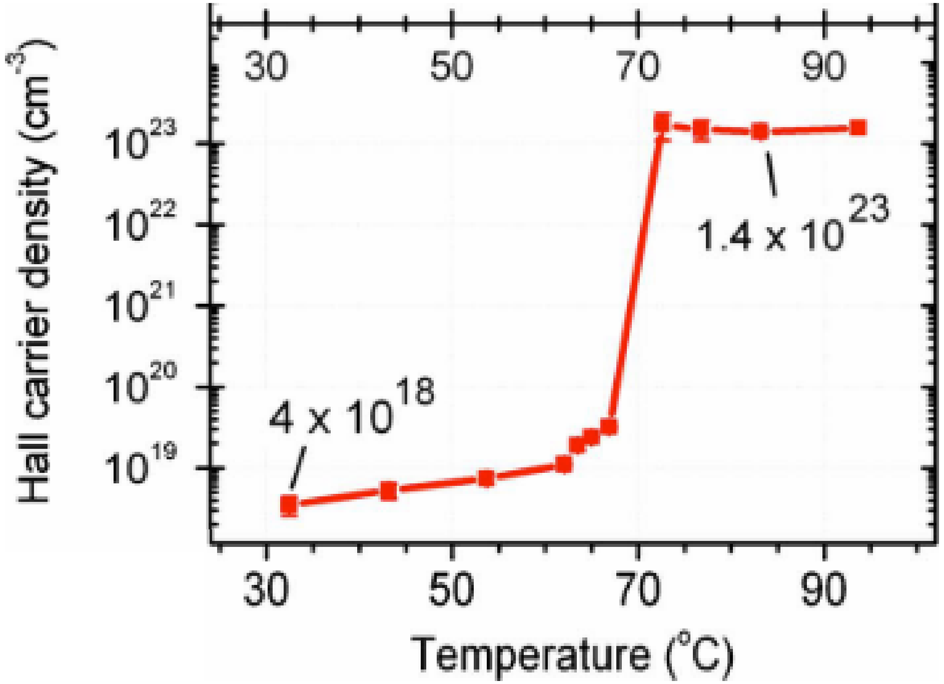


Fig 13. Electron transport properties of a thing film VO2 on an Al2O3 substrate (sample A) measured by 12 T sweeping field apparatus. The Hall-coefficient sign corresponds to electrons as the dominant current carriers.

Previews Studies

- *Song et. al* [7]:

The sign of the Hall voltage is negative; thus electrons are the predominant carrier in both semiconducting and metallic phases.

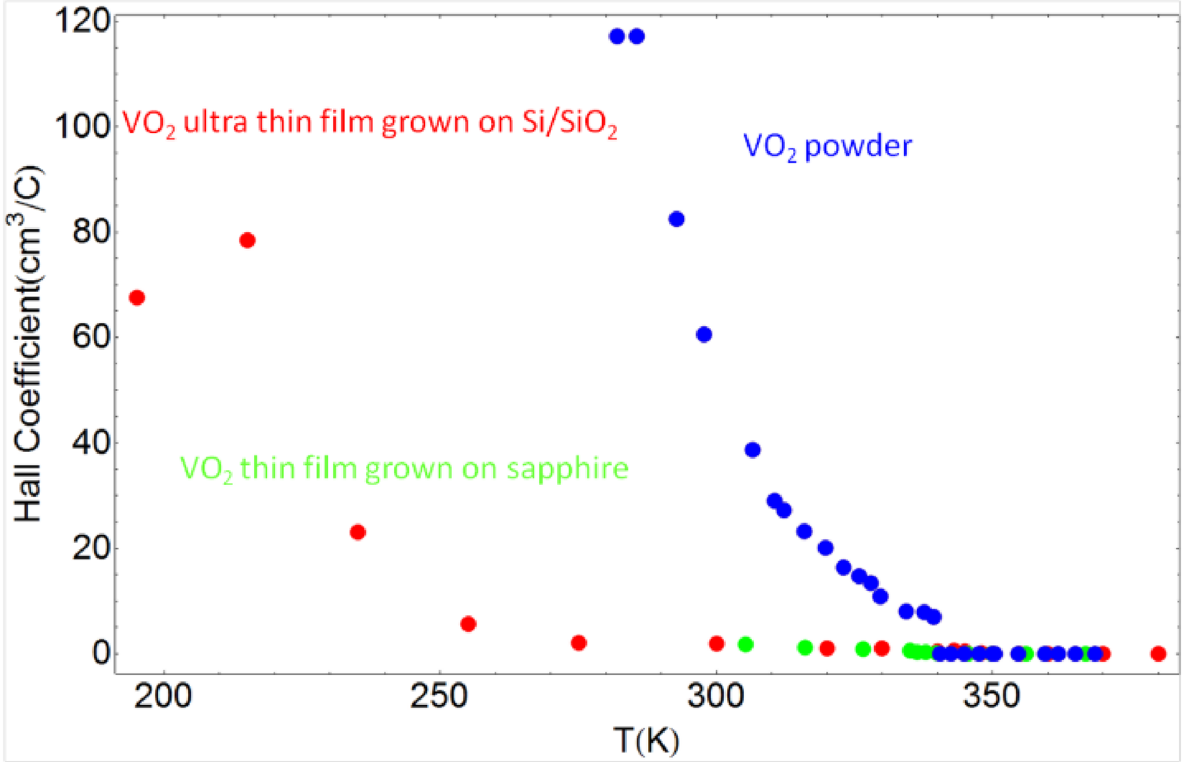


Fig 14. Temperature dependent hall coefficient.

My proposal

- Our main goal aims to grow vanadium oxides thin films as VO_2 and V_4O_7 and studies their magnetoresistance transport (properties) using the Hall effect taking advantage of the transitions that the material undergoes from metal to semiconductor since these occur at different temperatures.

My proposal

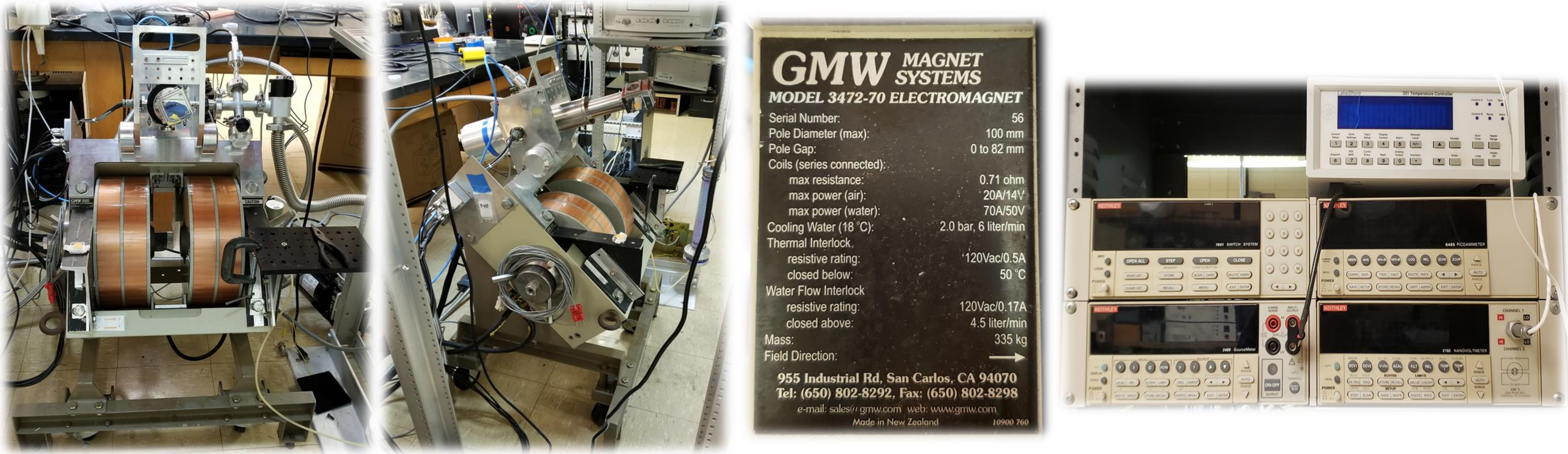


Fig 15. Hall equipment. (Resistivity Lab)

Preliminary Data

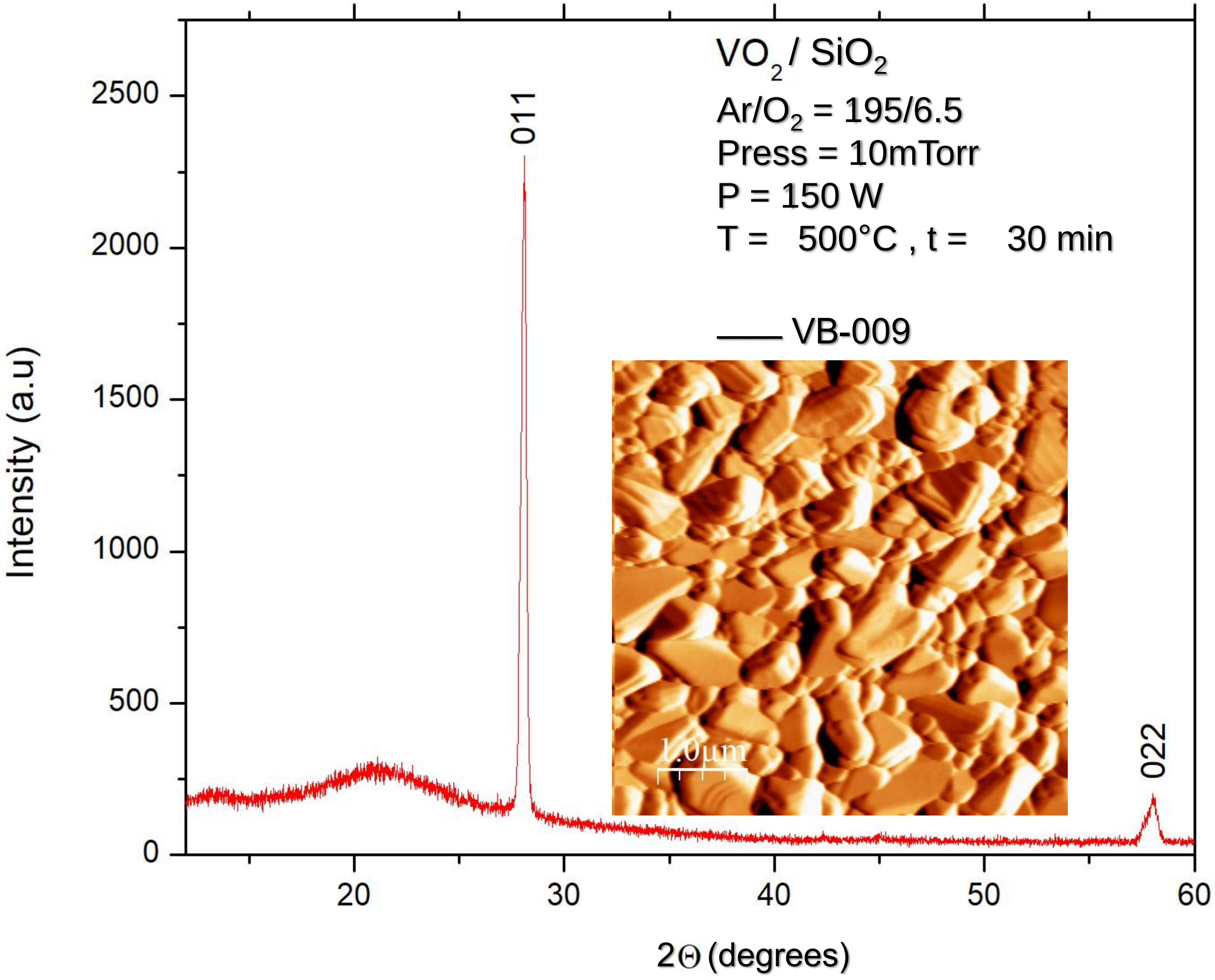


Fig 16. X-ray diffractogram and AFM results of VO_2 .

Conclusion

- Hall effect: It is voltage difference transversal to an electric current in a conductor due to perpendicular applied magnetic field.
- Van der Pauwn Technique: It is a method that could measure resistivity with a great precision.
- Vanadium oxides are metal-insulator materials that present a transition in a certain temperature accompanied by changes their properties, specially in their electrical properties.
- Using the Hall effect we are going to measure some electrical properties taking advantage of the transitions that the material undergoes from metal to semiconductor since these occur at different temperatures.

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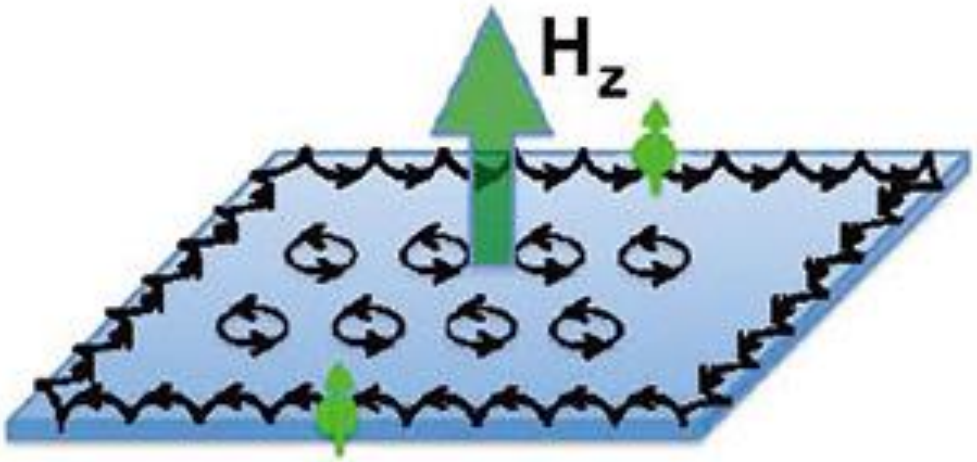
[5]] D. H. Hensler, Transport properties of sputtered vanadium dioxide thin films, J. Appl. Phys. 39, 2354 (1968).

[6]] D. Ruzmetov, D. Heiman, B. B. Claflin, V. Narayanamurti, and S. Ramanathan, Hall carrier density and magnetoresistance measurements in thin-film vanadium dioxide across the metal-insulator transition, Phys. Rev. B - Condens. Matter Mater. Phys. 79, 153107 (2009).

[7] F. Song, B. E. White Jr., Hall measurement of ultra-thin vanadium dioxide thin films, arXiv:1608.03378 (2016).

Thanks

Quantum Hall Effect



$$\sigma = \frac{I_{\text{channel}}}{V_{\text{Hall}}} = \nu \frac{e^2}{h} \quad \textbf{(8)}$$

The fractional quantum Hall effect is a variation of the classical Hall effect that occurs when a metal is exposed to a magnetic field. Classically, the Hall conductivity σxyσxy—defined as the ratio of the electrical current to the induced transverse voltage—changes smoothly as the field strength increases. But in high-quality two-dimensional systems such as gallium arsenide quantum wells or graphene, the Hall conductivity instead features plateaus quantized at (8), where e is the electron charge, h is Planck's constant, and ν is a rational number.