Phase Transistions

$R_s = \frac{V_{meas}}{I}$

$BaTiO_3$, $C = \frac{|V_{measured}|}{V_0 \omega R_0}$

$p \cdot 10^{-12}$

$V_0 = 1V$
$\omega = 25$ KHz
$R_0 = 1000\ \Omega$

We were only able to get 1 good run for both $BaTiO_3$ and VO_2

VO_2 $I = \frac{V}{R} = \frac{1V}{1M\Omega}$ accordin to Manual

$R_s = V_{meas}/I = \frac{V_{meas} R_0}{V_0} = V_{meas} \times 10^6$

$T_c = \frac{1}{2}(T_L + T_H)$ $T^* = \frac{1}{2}(T_c - T_L + T_H - T_c) = \frac{1}{2}(T_H - T_L)$

$\overline{T_{HL}} = \left(T_L/\sigma_L^2 + T_H/\sigma_H^2\right)\left(\frac{1}{\sigma_L^2} + \frac{1}{\sigma_H^2}\right)^{-1}$

Area and lenght appoxinations for ρ and A add for C_0
Why the large gap in R for VO_2

get value for ρ, σ_ρ, C_0, σ_{C_0}

~~Semi Conducting gap or rough line fit~~

~~Rough Erros for $BaTiO_3$ Capacitance~~

look at values that are far out

VO_2:
diameter $= .8913 \pm .00025$ in.

$BaTiO_3$
width $= 0.3406 \pm .00025$ in
lenght $= 0.2882 \pm .00025$ in

$.00025$ in $= 6.35 \times 10^{-6}$ M
$.8913$ in $= 0.0226$ M
$.3406$ in $= 0.00865$ M
$.2882$ in $= 0.00732$ M

VO_2

$$\rho = R\,\frac{A}{L}$$ - X Sectional Area / length

πd πr^2

1/6 width of Ba

.05

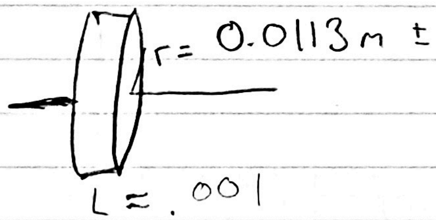
$BaTiO_3$

$$C_0 = \varepsilon_0 \frac{A}{d}$$ - X Sect. Area / - separat.

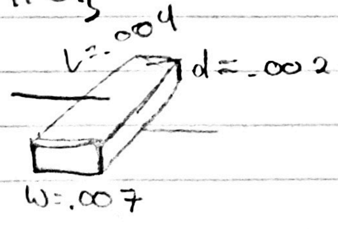
1/3 width Ba

0.00000635

VO_2



$BaTiO_3$



comparative?

V

VO_2 $R = V_{meas} \cdot \frac{R_0 (1M\Omega)}{V_0 \; 1V}$

Pg 8 • E_g $E_g > 2eV \Rightarrow$ good insulator

• Resistance ratio

• Absolut resistivity

• T_c ✓

• $T_{c\,coarse}^{*}$ ✓

• Temp of percolation transition T_M

Empty circuit? Pg 9

$BaTiO_3$ $C = \frac{|V_{meas}|}{V_0 \omega R_0}$ (1V)(25 KHz)(1000Ω)

• T_c

Calculate PG.15

C_0 is capacitance of empty capacitor of same geometry

PG 16 • Relitive dielectric constant K vs. T

$K = C_{BTO}/C_0$ $C_b = C(T_c)$, $C_{BTO} = \frac{C C_b}{C_b - C}$

46, read • Curie-Weiss law at $T > T_c$ and Curie-Weiss Const

• microscopic dipole moment p

• The atomic displacement x responsible for apperance of p

VO_2 TO DO

✓ Error determination
✓ χ^2 analysis

✓ Find T_c + Error

✓ Find T^* + Error $K_B = 8.617 \times 10^{-5}$ eV/K

eqn 7.

~~What is E_g Semiconducting gap~~
Calculate E_g
log ρ vs. $1/T$
Poster (0.428 ± .046 eV) poster lit (.7eV)

resistivity $\rho = \rho_0 \, Exp\left(E_g / 2K_BT\right)$

$\rho = R\frac{A}{L}$ A - Cross Section Area, L - length

$\rho = R\frac{A}{L} = R_0\frac{A}{L}\,Exp\left(E_g / 2K_BT\right)$

$\hookrightarrow \ln\left(\frac{R}{R_0}\right) = \frac{E_g}{2K_B}\left(\frac{1}{T}\right)$

$\hookrightarrow \ln(R) = \frac{E_g}{2K_B}\left(\frac{1}{T}\right) + \ln(R_0)$

✓ Calculate "Resistance ratio"
~~[illegible]~~
Poster (330)

Absolute resistivities in
- Semiconducting phase poster ($10^6\,\Omega$)
- Metallic phase ($10^4\,\Omega$)

✓ Percolation transition Temp T_M
When it effectivly becomes a metal
(I guess also find this for Semiconductors

~~Error~~ $\sigma^2_{Log(R)} = \left(\frac{\sigma_R}{R}\right)^2$ ✓

$K_B = 8.617 \times 10^{-5}\ eV/K$

$$\ln(R) = \frac{E_g}{2K_B}\left(\frac{1}{T}\right) + \ln(R_0)$$

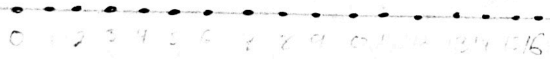
$$\text{Slope}\,(2K_B) = E_g$$

Simple linear regression

$$y = ax + b$$

$$\hat{b} = \bar{y} - \hat{a}\bar{x} \qquad \hat{a} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2}$$

x_1 has 473 x_2 has 536 Slope



looking for a slope at diffrent temps $1/\beta = T$

Slope at middle index $$\hat{a}_{\left(k + \frac{j-1}{2}\right)_M} = \frac{\sum_{i=k}^{k+j} (x_i - \bar{x}_M)(y_i - \bar{y}_M)}{\sum_{i=k}^{k+j} (x_i - \bar{x}_M)^2}$$

$\frac{1}{T}$ @ middel index $= \bar{x}_M$

$$\bar{x}_M = \frac{1}{j}\sum_{i=k}^{k+j} x_i$$

From $k = 0 \rightarrow k_{max} = 473 - j$

VO_2 Eqns

T_H, T_L, $R(T)$ given or found

T_c: $T_c = \frac{1}{2}(T_H + T_L)$ $\quad \sigma_{T_c} = \frac{1}{2}\sqrt{\sigma_{T_H}^2 + \sigma_{T_L}^2}$

T^*: $T^* = \frac{1}{2}\left(\left[T_H - T_c\right] + \left[T_c - T_L\right]\right) = \frac{1}{2}(T_H - T_L)$ $\quad \sigma_{T^*} = \sigma_{T_c}$

Absoulte resistivities:

$$\rho = R\frac{A}{L} = \pi R \frac{r^2}{L} \qquad \sigma_\rho^2 = \left(\frac{\pi r^2}{L}\right)^2 \sigma_R^2 + \left(\frac{2\pi r R}{L}\right)^2 \sigma_r^2 + \left(\frac{\pi R r^2}{L^2}\right)^2 \sigma_L^2$$

Semiconductor phase resistance

R_S = Weightd avg of $R(T = Low)$ for rising and falling

Metallic

R_M = " "$R(T = High)$" "

Resistace ratio:

$$\rho = \frac{R_S}{R_M} \qquad \sigma_\rho = \sqrt{\left(\frac{\sigma_{RS}}{R_M}\right)^2 + \left(\frac{R_S\,\sigma_{RM}}{R_M^2}\right)^2}$$

Semi Conducting gap E_g $\quad \rho = \rho_0 \, Exp\left(E_g / 2k_B T\right)$

$\hookrightarrow R = R_0 \, Exp\left(\frac{E_g}{2k_B T}\right) \rightarrow \ln(R) = \frac{E_g}{2k_B}\left(\frac{1}{T}\right) + \ln(R_0)$

See previous page for rolling value

Method 2: look at Slopes from $T = 40 \to 44$ and do weighted Avg

Weighted Avg / Error

$$\sigma_{\bar{x}}^2 = \left(\sum_{n=1}^{N} \frac{1}{\sigma_n^2} \right)^{-1} \qquad \bar{x} = \sigma_{\bar{x}}^2 \left(\sum_{n=1}^{N} \frac{x_n}{\sigma_n^2} \right)$$

$$C_0 = \varepsilon_0 \frac{A}{d} = \varepsilon_0 \frac{LW}{d}$$

$L = .0087 \quad \pm .0005$

$W = .0073$

$d = .002$

$$\sigma_{C_0}^2 = \varepsilon_0^2 \left[\left(\frac{W}{d} \right)^2 \sigma_L^2 + \left(\frac{L}{d} \right)^2 \sigma_W^2 + \left(\frac{LW}{d^2} \right)^2 \sigma_d^2 \right]$$

$\text{Pg } 10$

$C_0 = \varepsilon_0 \frac{A}{d}$ $\varepsilon_0 = 8.85 \times 10^{-12} \frac{F}{M}$

Capacitance of empty capacitor

Farads

$BaTiO_3$

$$k = \frac{C_{BTO}}{C_0} \qquad C_M = \frac{1}{\frac{1}{C_b} + \frac{1}{C_{BTO}}}$$

@ Phase Transition point $C_b \approx C_M(T_c)$
C_b is independent of temp

$$\text{So} \quad k(T) = \frac{C_M(T)\,/C_0}{1 - \left(C_M(T)/C_M(T_c)\right)} = \frac{C_M(T_c)\,C_M(T)}{C_M(T_c) - C_M(T)}\left(\frac{1}{C_0}\right) \qquad T \neq T_c$$

Curie-Weiss Laws

Electric Susceptibility $\chi_E \equiv dP/dE$

near a phase transition $\chi_E \gg 1$ and $T > T_c$

$$\chi_E \approx \frac{C_{cw}}{T - T_c} \quad \text{and} \quad \chi_E \approx \varepsilon$$

$$\text{So } k \approx \frac{C_{cw}}{(T - T_c)}$$

also note

$$\chi_E = \frac{1}{2a(T_c - T)} = \frac{2C_w}{T_c - T} \quad T < T_c \qquad \chi_E = \frac{1}{4a(T - T_c)} = \frac{C_{cw}}{T - T_c} \quad T > T_c$$

So below Slows have factor of 2

Plotting $\frac{1}{k} = \frac{1}{C_{cw}}(T - T_c)$ $\quad C_{cw} = \frac{1}{\text{Slope}} \quad \sigma_{cw} = \frac{1}{\text{Slope}^2}\sigma_{\text{slope}}$

Flxerkoas with C_0

$$P = \left(\frac{\varepsilon_0 k_B C_{cw}}{N}\right)^{1/2} \quad [C][n] \quad X = \frac{P}{6e^-}$$

$$N = \frac{1}{a^3} \quad a = .4\,nm$$

$$P = \sqrt{\varepsilon_0 k_B a^3}\; C_{cw}^{1/2}$$

$$\sigma_P^2 = \left(\frac{1}{2}\frac{\sqrt{\varepsilon_0 k_B a^3}}{C_{cw}^{1/2}}\right)^2 \sigma_{cw}^2 \qquad \sigma_P = \sigma_{cw}\left(\frac{\varepsilon_0 k_B a^3}{4 C_{cw}}\right)^{1/4}$$

$$K(T) = \frac{C_M(T_c)\, C_M(T)}{C_M(T_c) - C_M(T)} \left(\frac{1}{C_0}\right)$$

$$\sigma_K^2 = \left(\frac{C_M(T)^2}{C_0\,(C_M(T_c) - C_M(T))^2}\right)^2 \sigma_C^2 + \left(\frac{C_M(T)^2}{C_0\,(C_M(T_c) - C_M(T))^2}\right)^2 \sigma_C^2$$
$$+ \left(\frac{C_M(T_c)\, C_M(T)}{C_0^2\,(C_M(T_c) - C_M(T))}\right)^2 \sigma_{C_0}^2$$

$$\frac{1}{K} = \frac{C_M(T_c) - C_M(T)}{C_M(T_c)\, C_M(T)}\, C_0 \equiv \frac{C_c - C}{C_c C}\, C_0$$

plotting $\frac{1}{K}$ vs $(T - T_c)$

$$\sigma_{y\,tot}^2 = \sigma_y^2 + \left(\frac{dy}{dx}\right)^2 \sigma_x^2$$

$$\sigma_{1/K}^2 = \left(\frac{C_c - C}{C_c C}\right)^2 \sigma_{C_0}^2 + \left(\frac{C_0}{C_c^2}\right)^2 \sigma_{C_c}^2 + \left(\frac{C_0}{C^2}\right)^2 \sigma_C^2$$