Current bistability in insulators with large localization lengths

M. Ortuño

Universidad de Murcia

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Andrés M. Somoza (Universidad de Murcia)

C. Marrache-Kikuchi, L-H-H. To (CSNSM, University Paris-Saclay)

J. Gough and M. Pepper (University College London)

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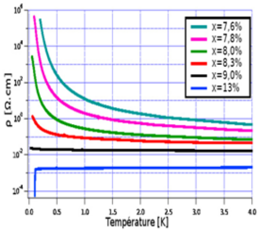
Outline

- Superconductor to insulator transitions
- Biestability in the insulating side
- Experimental results on Y_xSi_{1-x} thin films
- Hot-electron model
- Extended hot-electron model
- Experimental results on InSb thin films
- Conclusions

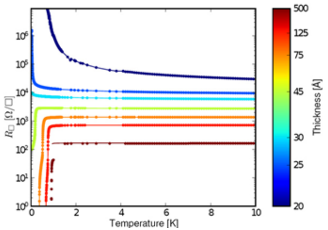
Superconductor to insulator transition

- Collaboration with experimental group of Claire Marrache-Kikuchi
- They can induce the transition by three different mechanisms

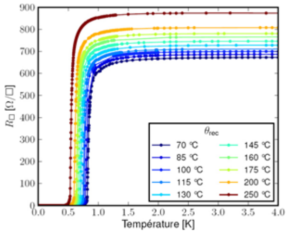
Composition



Thickness



Heat treatment

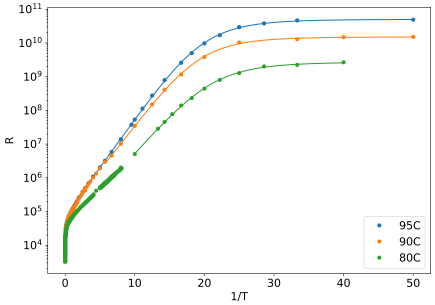


$\mathbf{Y}_x\mathbf{Si}_{1-x}$ thin films

Heat treatment

We consider insulating samples, close to the SIT

Effect of annealing



- Annealing increases disorder

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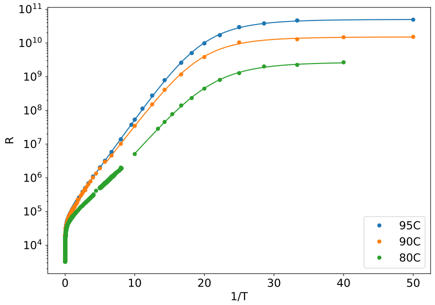
Effect of annealing

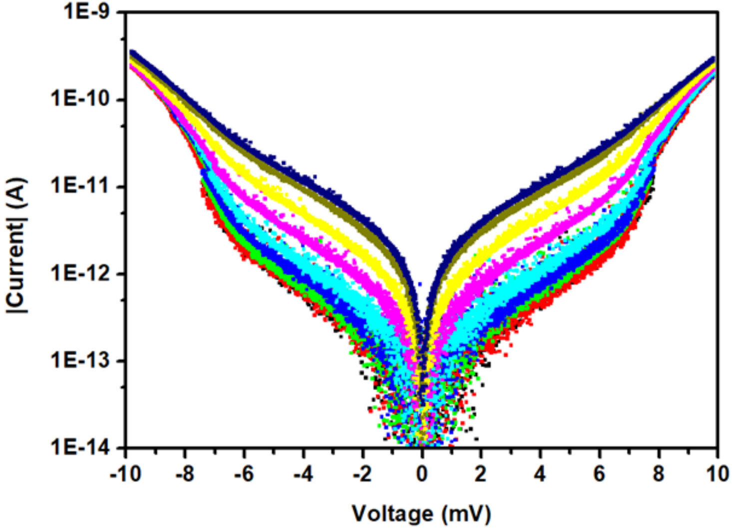


- Annealing increases disorder
- At low T, activated behavior
  - Mobility edge
  - Charging energy
  - Superconducting gap
  - Logarithmic interaction
  - Nearest neighbors

$Y_x Si_{1-x}$ thin films

$I-V$ curves

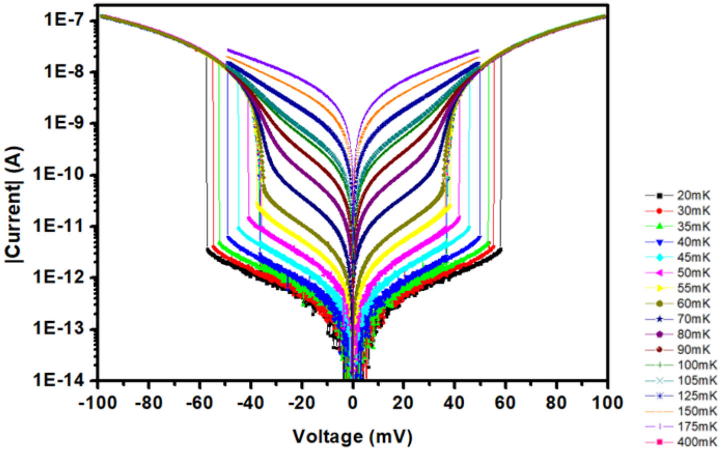
Annealing at $80°$



$\mathrm{Y}_x\mathrm{Si}_{1-x}$ thin films

$I-V$ curves

Annealing at $95°$



- Jumps in I by four orders of magnitude
- Strong hysteresis

Hot electron model

Similar results by Ovadia et al. (2009) and Ladieu et al. (2000)

They were explained by Altshuler et al. (2009) in terms of the hot-electron model (Wang, PRB, 1990)

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Effective temperature for electrons determines completely the resistance of the system $R(T, V) = R(T_{\rm eff}, 0)$:

$$\frac{V}{I} = R_0 \, \exp\left(\frac{T_0}{T_{\rm eff}}\right),$$

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$$\frac{V}{I} = R_0 \exp\left(\frac{T_0}{T_{\mathrm{eff}}}\right),$$

The effective temperature relaxes to the phonon temperature T by phonon emission. The dissipated power is equal to

$$P = \alpha(T_{\mathrm{eff}}^{\beta} - T_{\mathrm{ph}}^{\beta})$$

α related to the electron-phonon coupling.
Self-consistent equation for the effective temperature

$$\frac{V^2}{R_0} \exp\left(-\frac{T_0}{T_{\mathrm{eff}}}\right) = \alpha(T_{\mathrm{eff}}^{\beta} - T_{\mathrm{ph}}^{\beta})$$

Critical behavior

Critical point at

$$T_c = (\beta + 1)^{-\frac{\beta+1}{\beta}} T_0.$$

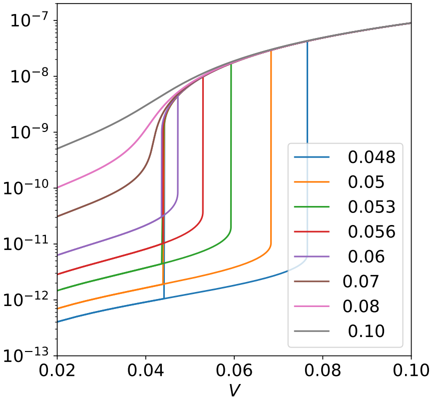
(parameter independent)

The critical voltage is

$$V_c = \sqrt{\frac{\alpha R_0 \beta T_0^\beta e^{\beta+1}}{(\beta+1)^{\beta+1}}}$$

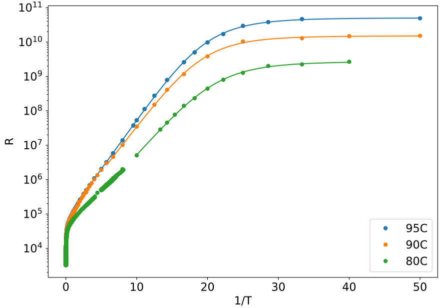
A similar transition should always occur for all insulating systems (maybe unobservable)

Hot-electron model



Linear regime

Saturation



- Saturation can be explained with the hot-electron model

$$P_{\text{ext}} = \alpha(T_e^{\beta} - T_{\text{ph}}^{\beta})$$

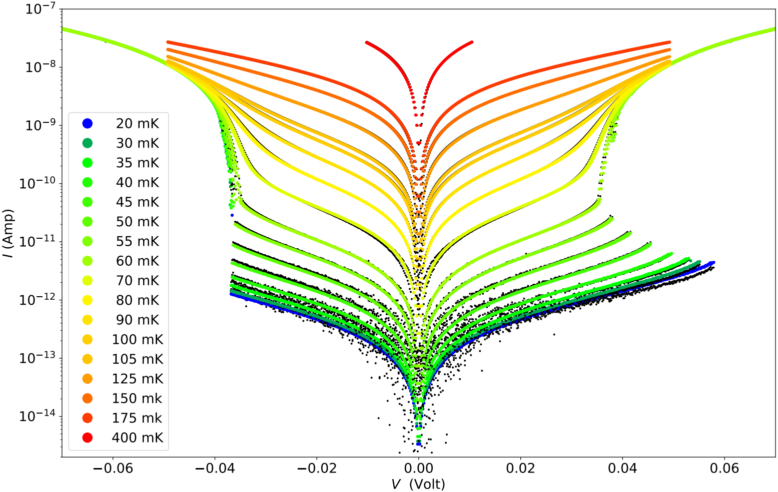
$$T_{\text{min}} = \frac{P_{\text{ext}}}{\alpha}^{1/\beta}$$

$$T_{\text{ap}}^{\beta} = T_{\text{ph}}^{\beta} + T_{\text{min}}^{\beta}$$

Fitting of experimental results

$I - V$ curves

Sample annealed at $95°$

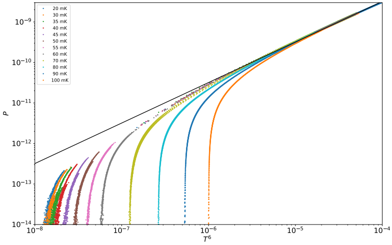


Free parameters: R_0, T_0, α (electron-phonon coupling), and P_{ext} ($\beta = 6$ fix)

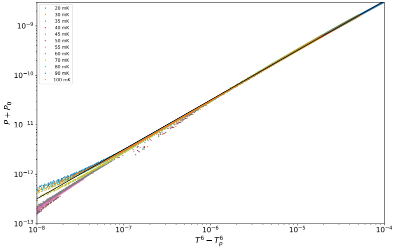
Dissipated power

$$P + P_{\text{ext}} = \alpha(T_{\text{eff}}^{\beta} - T_{\text{ph}}^{\beta}) \qquad \beta = 6$$

Power vs T_{eff}



Renormalized power

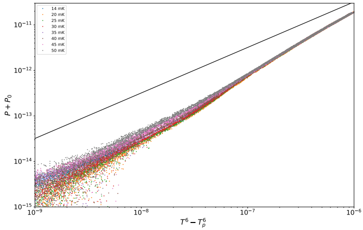


Sample annealed at $95°$

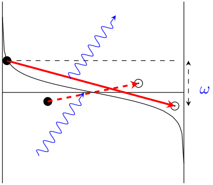
Dissipated power

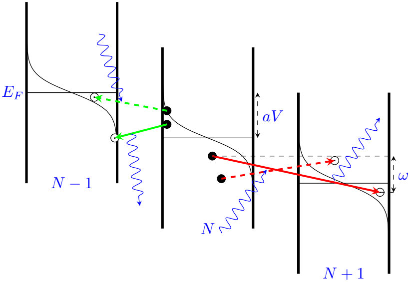
Sample annealed at $80°$

$\beta = 6$



- A second dissipation mechanism





$$P_2 = \alpha_2((T_{\rm eff} + aV)^\beta - T_{\rm ph}^\beta)e^{-\frac{T_0 - aV}{T_{\rm eff}}}$$

Fitting of experimental results

$I - V$ curves

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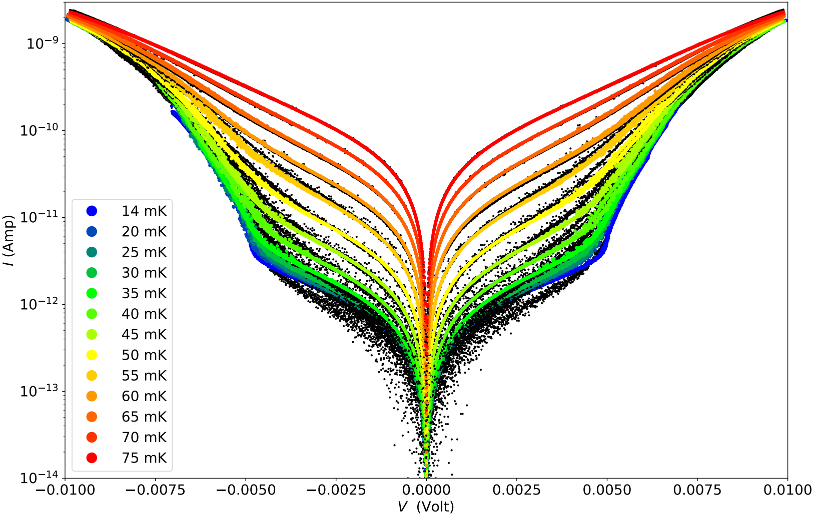
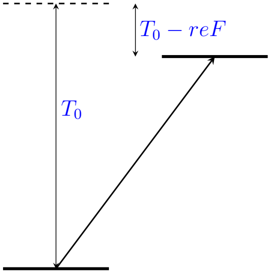


Non-linear effects

We include the standard exponential field-effect in hopping conduction

$$R = R_0 \exp\left(\frac{T_0 - aV}{T_{\text{eff}}}\right)$$



$$a = \frac{er}{2L} \qquad r \approx \xi$$

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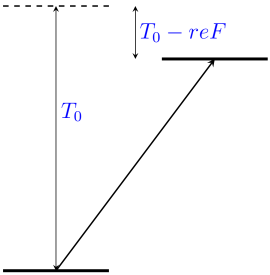

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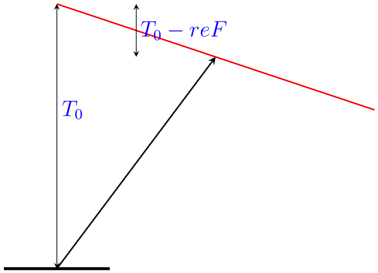
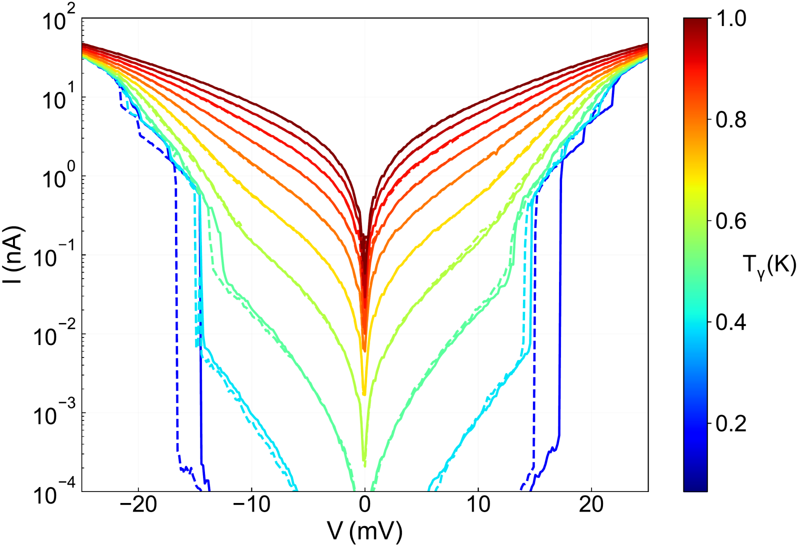
The same effect should appear in an upper Hubbard band



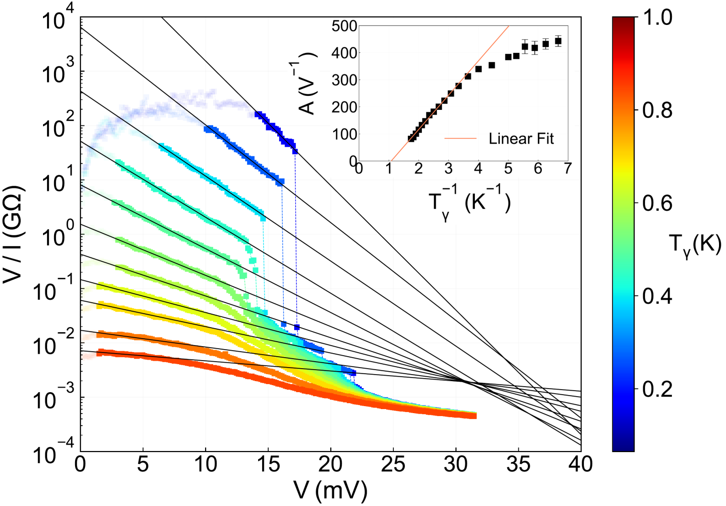
Experiments on InSb thin films

- J. Gough and M. Pepper, UCL



Experiments on InSb thin films

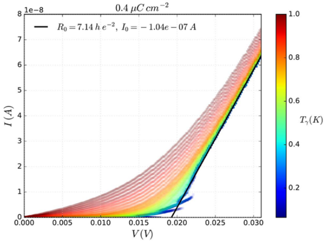
- Exponential field-effect



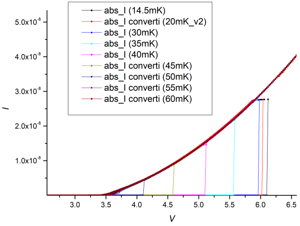
- No hot-electron effects

$I - V$ curves

InSb thin films

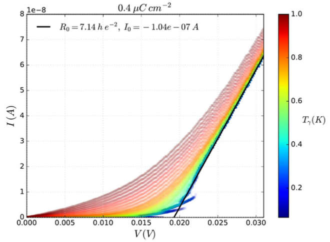


$Y_x Si_{1-x}$ thin films

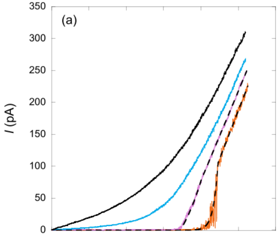


$I-V$ curves

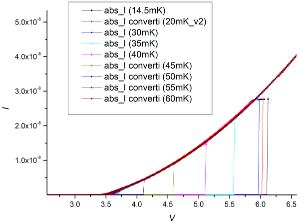
InSb thin films



MOSFETs



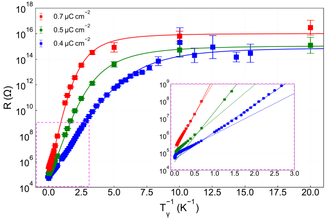
Y_xSi_{1-x} thin films



- Claimed (by Munyan, Stemmer) to be a Wigner physics effect
- Transition from solid (glass) to fluid
- Avalanches

Overactivation

InSb thin films



- In disordered InSb with a large localization length, overactivation is observed
- In Y_xSi_{1-x} thin films the overactivation was ascribed to the superconducting gap
- Saturation is also relevant in InSb, but probably with a different origin than in Y_xSi_{1-x}

Conclusions

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- Excelent procedure to determine the localization length ξ
- Understanding of nonlinear effects in hopping
- There are at least two types of bistabilities

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Open questions

- Nature of the activation energy
- Role of superconductivity