Imaging thermoelectric power at the nanoscale

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2017, March 21st
Outline

1. Transport in Quantum Point Contacts (QPCs)

2. Thermopower
   - The Seebeck coefficient
   - Thermopower of quantum point contacts
   - The Mott relation

3. Scanning gate thermoelectric microscopy
   - Scanning gate microscopy
   - SGTM on a QPC
   - SGTM on an InGaAs network

4. Conclusion
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4 Conclusion
High mobility 2DEG are grown in LPN, Marcoussis

- Model two-dimensional systems
- Platform to study ballistic transport
- Interesting thermoelectric properties
Quantum Point Contacts (QPC)

Simplest quantum electronic device built in these structures:

QPC conductance is quantized by steps of $2e^2/h$

First realized in 1988:
B. J. van Wees *et al.*, Phys. Rev. Lett (Delft)
D A Wharam *et al.*, Journal of Physics C (Cambridge)
The attached video can be found [here](#).
Feel free to use it on pedagogical purposes.

Visual: Benjamin Kuperberg
Quantum Point Contacts (QPC)

Each mode contributes for $2e^2/h$ to the conductance

\[ \text{E}_f \]

\[ U \]

\[ y \]

\[ V_0 \]

\[ n=1 \]

\[ n=2 \]

\[ n=3 \]

\[ \hbar \omega_y \]

\[ \hbar \omega_x \]
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Discovery of the thermopower: 1821

Thomas Johann Seebeck
Discovery of the thermopower: 1821

conductor
Discovery of the thermopower: 1821

\[ T + \Delta T \quad \text{conductor} \quad T \]
Discovery of the thermopower: 1821

![Diagram of thermopower concept]
Discovery of the thermopower: 1821

Seebeck coefficient:

\[ S = \frac{\Delta V}{\Delta T} \]

Order of magnitude for metals: \(-100 \mu V/K < S < +100 \mu V/K\)
Discovery of the thermopower: 1821
Discovery of the thermopower: 1821
Thermopower of quantum point contacts

Differential conductance: $G = dI/dV$

$\mu_R = \mu_L + eV$

$\tau(E)$ vs $E$
Thermopower of quantum point contacts

Quantum Oscillations in the Transverse Voltage of a Channel in the Nonlinear Transport Regime

L. W. Molenkamp, H. van Houten, C. W. J. Beenakker, and R. Eppenga
Philips Research Laboratories, 5600 JA Eindhoven, The Netherlands

Differential conductance: \( G = \frac{dI}{dV} \)

\( \mu_R = \mu_L + eV \)

Thermopower: \( S = \frac{dV}{dT} \)

\( T_R = T_L + \Delta T \)
Measurement setup

Differential conductance

\[ f_\ell \quad \text{Lock-in 2} \quad U \]

\[ V_g \quad I \]

\[ \text{Lock-in 1} \quad f_\ell \]

\[ \text{imc}n \]

\[ \begin{align*}
G(\frac{2e^2}{h}) & \quad 6 \\
V_g(V) & \quad -0.7 \quad -0.6 \quad -0.5 \quad -0.4 
\end{align*} \]
Measurement setup

Differential conductance

\[ U \]

Thermopower

\[ 2f_h \]

\[ U_{\text{th}} \]

\[ \text{Vg} \]

\[ f_t \]

\[ f_h \]

\[ V_{\text{ac}} \]

\[ f_t \]

\[ V_{\text{ac}} \]

Graphs:

- Conductance vs. \[ V_g \]
- Voltage vs. \[ V_g \]

Institute:

IMCN

Boris Brun (FNRS)
The Mott relation

Mott relation:

\[ S_{\text{Mott}} = -\frac{\pi k_B^2 T}{3e} \frac{1}{G} \frac{\partial G}{\partial \mu} \propto \frac{1}{G} \frac{\partial G}{\partial V_g} \]
The Mott relation

Mott relation:

\[ S_{Mott} \propto 1/G \frac{\partial G}{\partial V_g} \]
The Mott relation

Mott relation:

\[ S_{Mott} \propto \frac{1}{G} \frac{\partial G}{\partial V_g} \]
The Mott relation

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Scanning gate microscopy: principle

Westervelt group, Harvard, 1996
Self-sensing tips

Laser detection of the cantilever is forbidden, therefore:

- Use of piezoelectric cantilever, home-coated
- Glue a tungstene wire (eventually FIB-etched) on a tuning fork
- Glue a commercial tip on a tuning fork
Scanning gate microscopy: principle

Scanning gate microscopy: principle

(Westervelt group, Harvard)
Scanning gate microscopy: principle

See also: M. A. Topinka et al., Nature 410 (2001).
The attached video can be found here
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Visual: Benjamin Kuperberg
Imaging quantum transport

Experiments:

![Image of two plots showing G(2e^2/h) vs. y(μm) and x(μm)]
Imaging quantum transport

Calculation:

$|\psi_t|^2$ (a.u.)

$G(2e^2/h)$
Imaging quantum transport
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Imaging quantum transport

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Scanning Gate Thermoelectric microscopy

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Conclusion

- We explore thermopower of two-dimensional electron gases

- A local approach has been developed, inspired by scanning gate microscopy

- In the future, we will focus on other signals (thermal conductivity and Peltier coefficient) and on different materials (graphene)
Conclusion

Thank you,
and let’s go to the Spa!