Quantum Nano Physics: yesterday today tomorrow

Yuli V. Nazarov Department of Quantum NanoScience Kavli Institute of NanoScience Delft University of Technology The Netherlands Квантовая нано-физика как жизнь и развлечение: что было, есть и будет (с вами)

> Юлий Назаров Красноярск=>Физтех=>Делфт 1960=>1976=>1993

Nanoscience

 A single phrase to compress the essence of natural sciences

- Everything consists of atoms
- NanoScience everything consists of atoms
 - Shaping the world atom by atom
 - Democritus, Epicurus
 - Recently proven experimentally







Quantum Nanosciene as a part of Nanoscience

- Quantum transport
 - Yes, it consists
 - Single sentence: this is not important...

Nanostructure

- Small?
- Conductance scale
- Energy/frequency scale:
 - voltage
 - Temperature (currently low)

Overview of the field

Classical-quantum
Continuous-discrete
Metal-insulator
Interacting- non-interacting



Yesterday: Josephson









First fundamental device ever 1962

- Gave rise to quantum nanoscience
- Superconductors: coherent state

$$\frac{d\phi}{dt} = \frac{2e}{\hbar}V \qquad I = I_{sin}\phi$$

Quantum interference applications

- Generation applications
- Qubit applications



Yesterday: Quantum point contact

- **1988**
- Quantization of conductance
- Electrons are waves
- Resistance is scattering
- Channels
- Transmissions T_p



• Landauer formula



Yesterday: Quantum computing

Qubits versus bits

2

states

$$\alpha |0\rangle + \beta |1\rangle, |\alpha|^2 + |\beta|^2 = 1$$

N bits: 2^N states

 $|0\rangle$ or $|1\rangle$

To present N qubits: M bits,

N qubits:
$$2^{N}$$
 dimensions
 $M = 64 \Box 2^{N}$



- Quantum algorithms
- Shor,1993: they beat classical





Solid-state-based qubits





Spin Charge Phase Flux

5 µm



Today:two-qubit quantum processor Nature, July 2009, DiCarlo et.al



Manipulation of the quantum state Characterization of density matrix Proof of the concept





Today: Resonance Fluorescence of a Single Artificial Atom, Science, Feb. 2010







And now let us rise the power



Today:Single-Electron Tunneling and Nanomechanical Motion, Science Aug. 2009



Frequency shift Mechanical instabilities Electro mechanical instabilities



Tomorrow:?

- Goals: control, complexity, elegance
- First device paradigm
 - Circuit, classical elements
- Second device paradigm
 - Quantum computing with quantum states
- Third device paradigm

• Use of quantum fiels: infinitely many degrees of freedom

