4th Workshop: Elaboration of Recommendations

Technology and Design of new computing paradigms

Rapporteurs:

G Fagas (Tyndall), C M Sotomayor Torres (ICN), G Wendin (Chalmers) and D Winkler (Chalmers)

INPUTS FROM:

Speakers, Discussants, Rapporteurs:

NANO-TEC WS1

Quantum Computation and Molecular Electronics

Speaker: Göran Wendin, Chalmers University of Technology, Gothenburg, Sweden
Discussant: Douglas Paul, University of Glasgow, United Kingdom
Rapporteur: Dag Winkler, Chalmers University of Technology, Gothenburg, Sweden

NANO-TEC WS2

Solid-state Quantum Computing

Speaker: Jaw-Shen Tsai, Smart Energy Research Laboratories, NEC Corporation, Japan
Discussant: Wolfgang Porod, University of Notre Dame, USA
Rapporteur: Isabelle Ferain, Tyndall National Institute, Cork, Ireland

Memristors

Speaker: Julie Grollier, CNRS-Thales, Palaiseau, France
Discussant: Dag Winkler, Chalmers University of Technology, Gothenburg, Sweden
Rapporteur: Clivia M. Sotomayor Torres, Catalan Institute of Nanotechnology, Barcelona, Spain

INPUTS FROM:

Speakers, Discussants, Rapporteurs:

NANO-TEC WS3

Quantum Computing

Speaker: Göran Wendin, Chalmers University of Technology, Gothenburg, Sweden
Discussant: Jouni Ahopelto, VTT Technical Research Centre of Finland, Espoo, Finland
Rapporteur: Piotr Grabiec, Institute for Electron Technology, Warsaw, Poland

Neuromorphic Computing

Speaker: Julie Grollier, CNRS-Thales, Palaiseau, France
Discussant: Dag Winkler, Chalmers University of Technology, Gothenburg, Sweden
Rapporteur: Clivia M. Sotomayor Torres, Catalan Institute of Nanotechnology, Barcelona, Spain

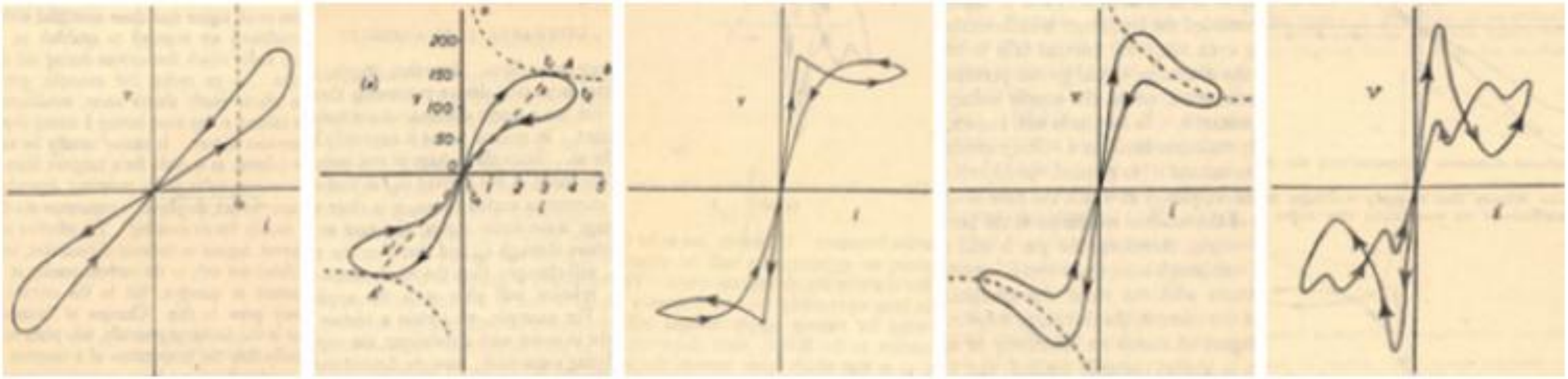
The computer of the future (2046)?

INTRODUCTION

Processing in the brain is facilitated by the adjustable synaptic weight between two neurons

Neuromorphic computing → delivered by memristor

Memristor: conductance can be continuously tuned through the past history of state variables



Themistoklis Prodromakis, Christofer Toumazou and Leon Chua
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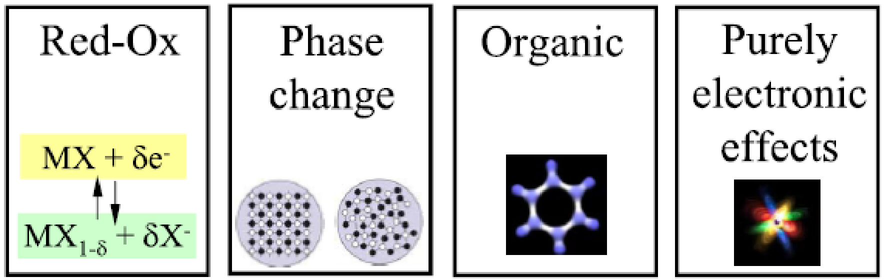
INTRODUCTION

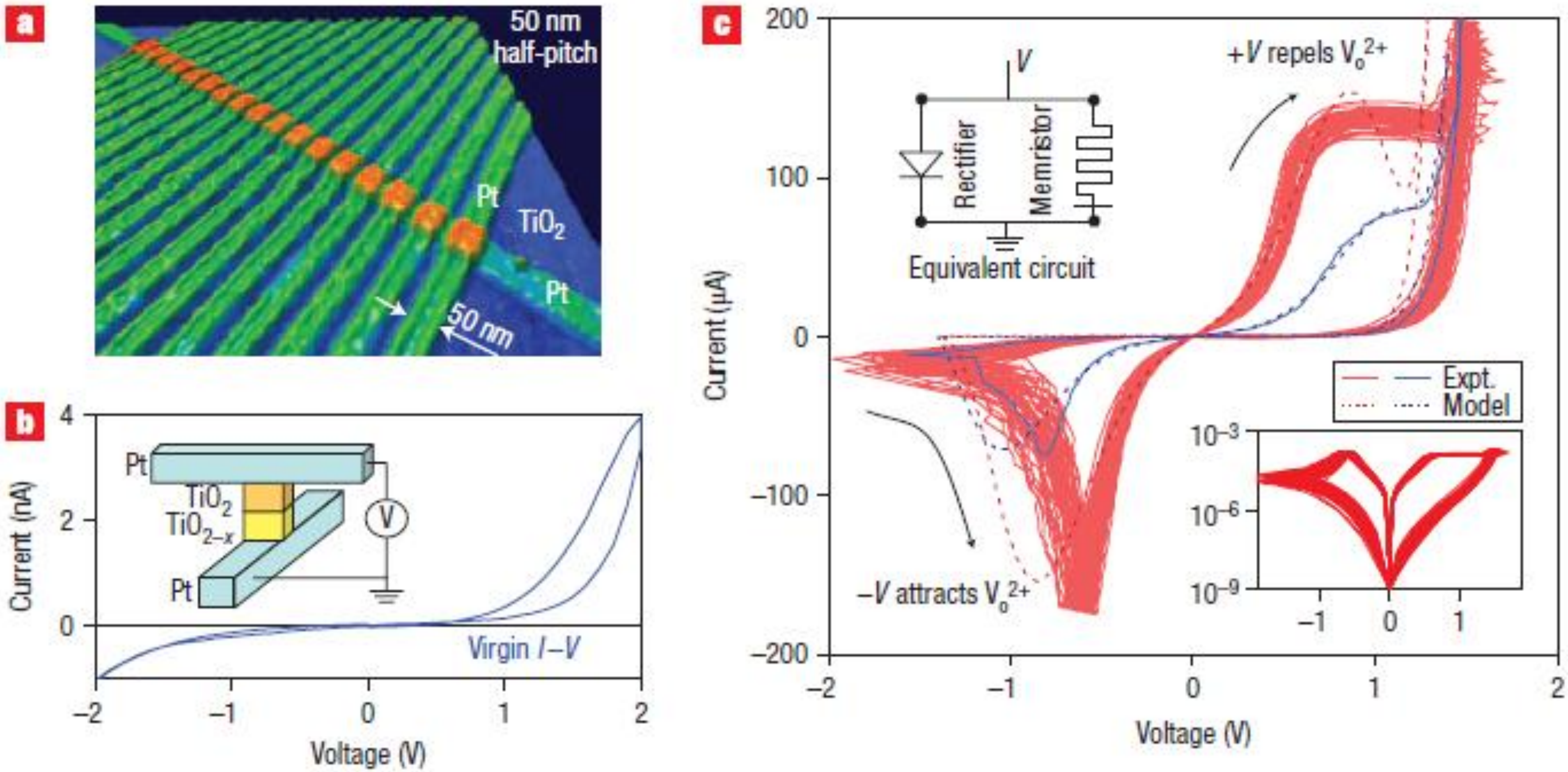
Examples of Devices and Concepts: Neuromorphic Computing

- Main characteristics
  - Based on MEMRISTOR type devices
  - "Plasticity"
  - Digital memory
  - Logic and neuromorphic functions 10ns with less than 1pJ power consumption
- Principle of operation



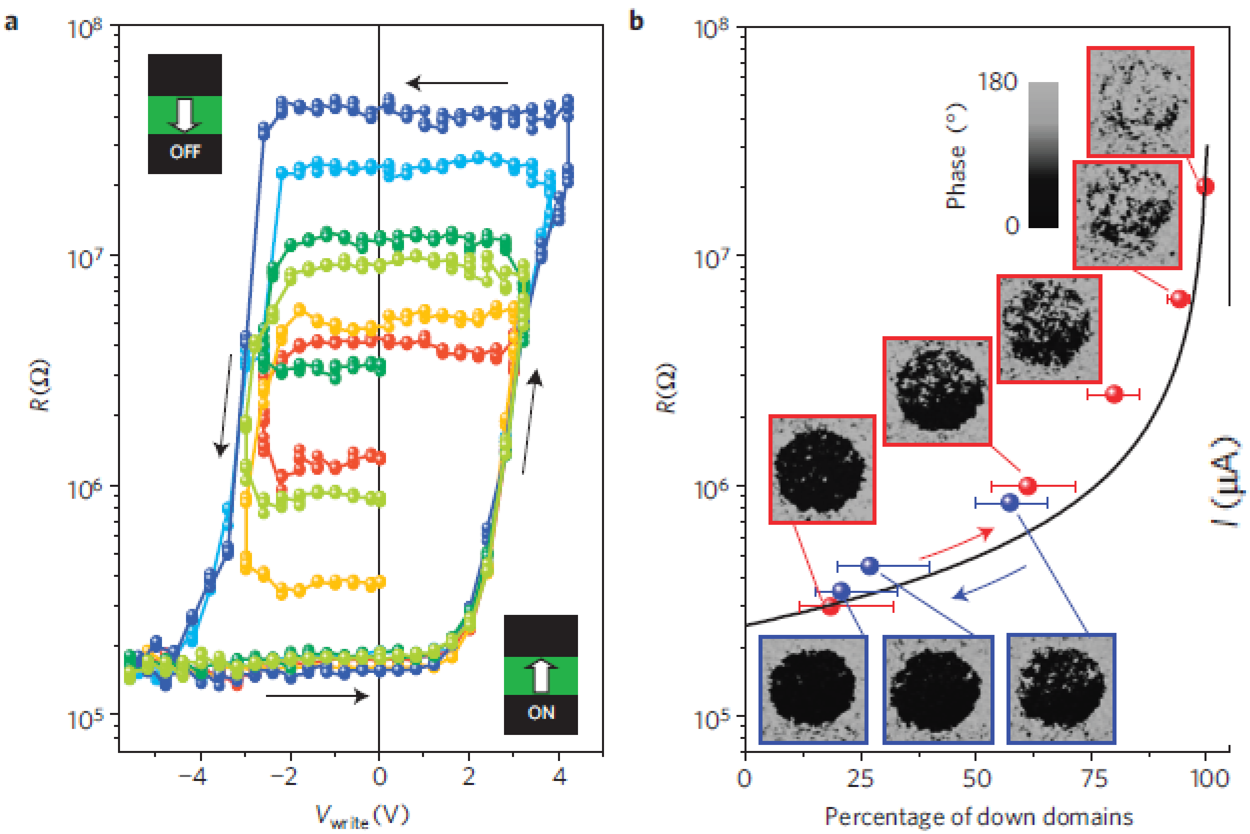
- Context of B CMOS - possibly develop:
  - the robotics area
  - associative learning
  - efficient image processing

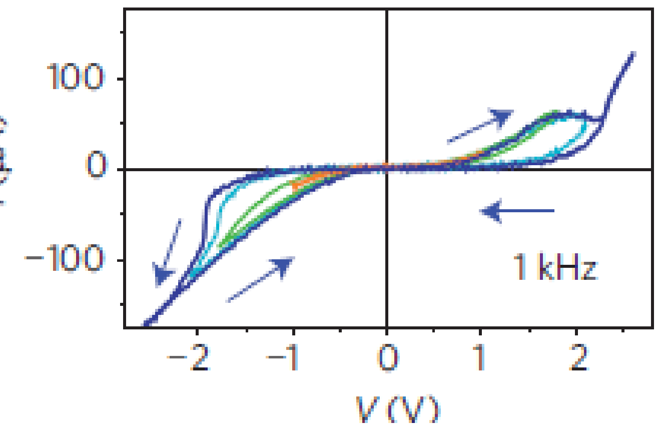
Bipolar reversible and nonvolatile switching of nanoscale TiO_{2-x} devices



J. Johsua Yang *et al*
nature nanotechnology | VOL 3 | JULY 2008 | 429

A ferroelectric memristor





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Quantum Computation

- Main characteristics
  - Rests on principles of quantum nature of states
  - Quantum coherent state – need of long coherence time

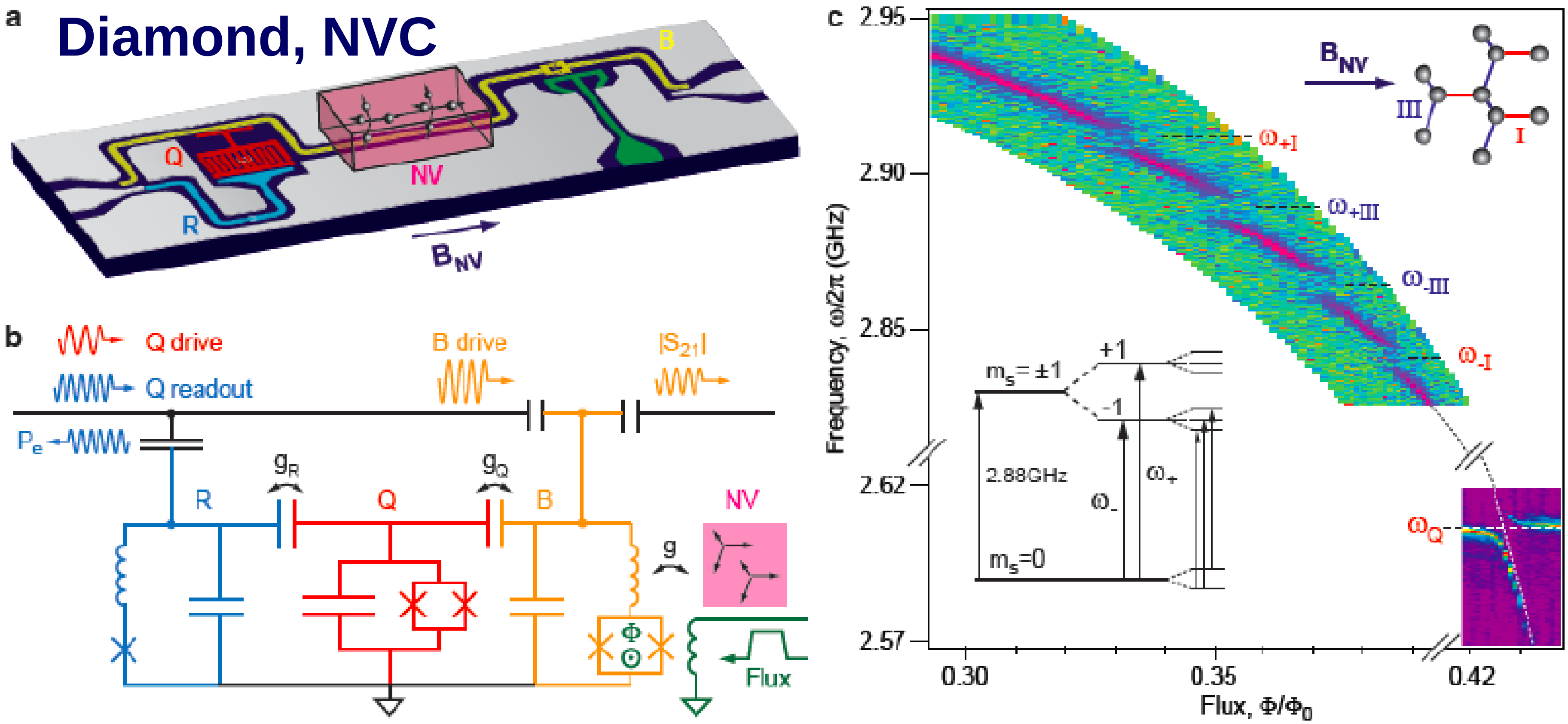
- Principles of operation (solid-state approaches)
  - JJ-based Transmon qubit - resonator (cQED) systems (30 mK)
  - Spin-based NV centers in diamond (300 K)

- Context of B CMOS
  - Speed for some problems polynomial while exponential for classical systems
  - Only special algorithms, e.g., factorization, data base searches

- Focus areas:
  - Teleportation
  - Measurement-based feedback and feed-forward
  - Quantum error correction (QEC)
  - Simulation of quantum system

QIP hybrid devices, state of the art

Diamond, NVC



Quantronics group, CEA-Saclay, France (2011)

Diamond, NVC for RT QIP: Wrachtrup group, Stuttgart; Hanson, Delft; Lukin group, Harvard; Awschalom group, UCSB; ….

Timescales for quantum information processing

- The next 4-5 years may be decisive and reveal a realistic timescale for competitive quantum information processing.
- A realistic guess is 5-10 years for highly significant applications for simulation of physical models and communication of information.
- These include a variety of quantum systems: ions, atoms, impurity spins and superconducting circuits.

RECOMMENDATIONS

Problems to address – Neuromorphic Computing

- Concerning memristors the material and physical changes required for operation needs to be studied with respect to defect tolerances, reproducibility and the reversibility of the thermodynamic processes involved.
- At present, for switching functionality, the I-V loops indicate large dissipation. Therefore, local heating, which impacts power consumption, needs to be addressed, as well as co-firing and fan-out and scalability bounds need to be defined.
- Highly non-linear processes are involved which require an adequate theoretical framework.
- New architecture concepts will be needed in order to take into account that each memristor-based device will vary and therefore can process information differently.
- New architecture will also be needed to optimise inter-connectivity at neural level thereby improving the understanding of processes related to learning and transfer of training.

Problems to address (cont'd) – Neuromorphic Computing

- The plasticity aspect can probably be tackled also by working on the pulse shape rather than on the material, in order to obtain more states with a controlled potential. For this, active memristors will be needed to test algorithms and their transferability.
- Memristor types suitable as devices for neuromorphic computing applications need to be identified together with a killer application for memristors to be successful. A possible candidate is pattern recognition based upon a CMOS "neuron" in conjunction with memristor "synapses".

Problems to address (cont'd) - Quantum Information Processing

- On the classical side, applications may include approaches to solve problems that classical may include efficient simulation of the physics of quantum systems, materials science and biomolecular systems, as well as implementation of extremely sensitive measurement devices and interfaces.

Future Activities…

- A cross-disciplinary “super IP” (10-20 MEuro/year during 5 + 5 years) is essential as a real R&D project1, not a loosely organised program.
- Within such a "super-IP", quantum computing and neuromorphic computing should be embedded in digital environments via digital-analogue hardware and software interfaces, in order to create useful hybrid systems.
- Such a "super IP" should pave the way for important commercial applications in 5-10 years.