NanoSciences and Atom-Technology


Research Type: Theory

Quantum Information Processing and Communication

Contribution from CEMES CNRS UPR 8011

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Activity summary

CEMES is developing quantum technology based on a dual approach using (1) single molecular design and atom manipulation on surfaces to create quantum circuits and logic gates and (2) plasmonic circuits and modal logic gates coupled to single photon sources (QIPC 4.2[1]). By a combined theoretical and experimental effort sustaining both approaches, CEMES aims at downsizing quantum information processing and communication to devices with footprint as small as 1 nm² and interconnects as narrow as 1 nm, a formidable challenge for miniaturizing the mainstream QIPC paradigms (qubits or trapped atoms). Quantum control in a nanometer-scale single molecule or atom circuits is achieved by manipulating electronic quantum states by the presence of adatoms in order to implement quantum logic gates and, in the longer term, by using single molecule latching (QIPC 4.2, 4.3.1). Quantum computing is explored with magnetic molecular qubits but also with a range of qubit-free atomic-scale quantum systems using the new Quantum Hamiltonian Computing approach. With quantum plasmonics, optical qubits, namely colored centers in nanodiamonds, are coherently coupled through a delocalized quantum plasmonic mode sustained by crystalline plasmonic structures (QIPC 4.1.2-4.1.5). Such architectures are implemented to investigate and minimize the decoherence-dissipation link and allow the emergence of superposition states in an entanglement regime, which could be used for the design of single photon transistors and substrate-borne optical quantum logic gates. Both approaches offer ways to long range transfer quantum information and correlate quantum states through atomic-scale quantum channels such as molecular wires, atom wires or single plasmon waveguides (QIPC 4.1.2 - 4.1.5). The dual nature of plasmon modes (electron-photon) offers an opportunity to interface electronic and optical quantum computing and quantum information transfer devices. It also provides a way to reach larger bandwidth for the study of quantum dynamics. On the other hand, the quantum-classical and classical-quantum conversion is studied at the input and output of atom circuits or single molecule logic gates to exploit quantum decoherence instead of avoiding it (QIPC 4.3.4, 4.5). Finally, theory of the control and coherence of state space trajectory, complex logic gate design, zero effective mass tunneling, and quantum plasmonics description is carried out (QIPC 4.3).

Detailed expertise

1. Quantum control theory (QIPC 4.3)

Theory : Trajectory in state space. Decoherence and trajectory control by modifying the Hamiltonian generating the quantum evolution on the Bloch hypersphere. Quantum control robustness.

2. Qubit-based quantum computing (QIPC4.2.6)

*Experimental*: Synthesis and spectroscopy probing of a molecule-SWAP

*Theory*: Design of intramolecular qubits in complex multicenter mixed-valence compounds.


3. Qubit-free quantum computing (New section QIPC 4.2.7 ? (exp.), 4.3.1 (theor.))

*Quantum atom circuits*: Implementation of a NOR gate with 10 dangling bonds on Si(100)H surface. Design of all 2-inputs, 1-output Boolean logic gates. Bistable molecules as logic input.


*Quantum molecular logic gates*: Manipulation of electronic states in a single molecule by using single Au atoms as inputs. Implementation of a NOR, a XOR gate and an analogic adder.


*Quantum plasmonic logic gates*: Implementation of multiple input/output reconfigurable logic gates in confined 2D plasmonic architectures for high speed bosonic transfer functions at room temperature. The quantum plasmonic state is populated from a quantum photon source.


*Theory*: Quantum graph theory applied to the design of bollean logic gates. Quantum Hamiltonian Computing so far up to a 2x2 bit adder with carry.


4. Quantum communication in complex circuits (QIPC 4.1.2 to 4.1.5)

*Experimental*: 2D plasmon mode design for long distance quantum information transfer and modal logic gate implementation. Decoherence control and coupling of single photon source to single plasmon for plasmon-mediated long distance entanglement. Quantization of plasmon in nanoscale 1D channels for quantum information transfer.
Super tunneling; long distance state correlation through an atomic scale quantum channel: atom wire, low effective mass molecular wires. Very long distance tunneling for quantum information exchange in complex quantum computing structures. Modulation of the long-range intramolecular spin-spin entanglement with the magnetic molecular orbital topology. 


**Theory:** Complex value band theory, zero effective mass in tunnelling regime. Entangled states in Hilbert space.


5. Atom Technology (QIPC 4.3.4 & 4.5)

**Experimental:** Atom-by-atom construction of Boolean quantum Hamiltonian logic gates at a semi-conductor surface with the low-temperature, UHV 4 probe STM in CEMES PicoLab.


**Theory:** Classical-quantum and quantum-classical conversion theory for atomic or molecular circuit input/output. Band structure optimization for metallic nanopads and pointer states.


[1] Refers to sections of the QIPC roadmap (version 1.8) which can be found at: [http://qurope.eu/content/qipc-roadmap](http://qurope.eu/content/qipc-roadmap) [3]
- Quantum Engineering [4]
- Quantum Computation [5]

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