Quantum Confinement in Security Elements

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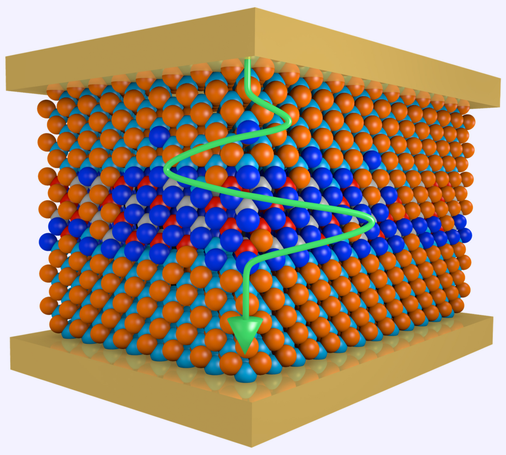
Quantum Base

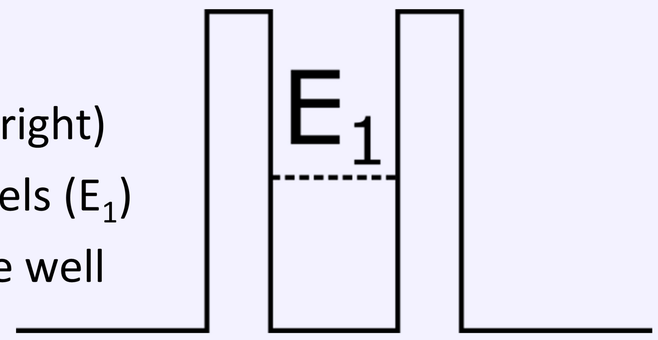
1) Introduction to Quantum Confinement and Resonant Tunnelling Diodes

Quantum confinement occurs when a particle such as an electron is confined on the length scale of its wavelength. When an electron is strongly quantum confined, it can only exist at discrete energy levels.



Resonant Tunnelling Diodes (RTDs):

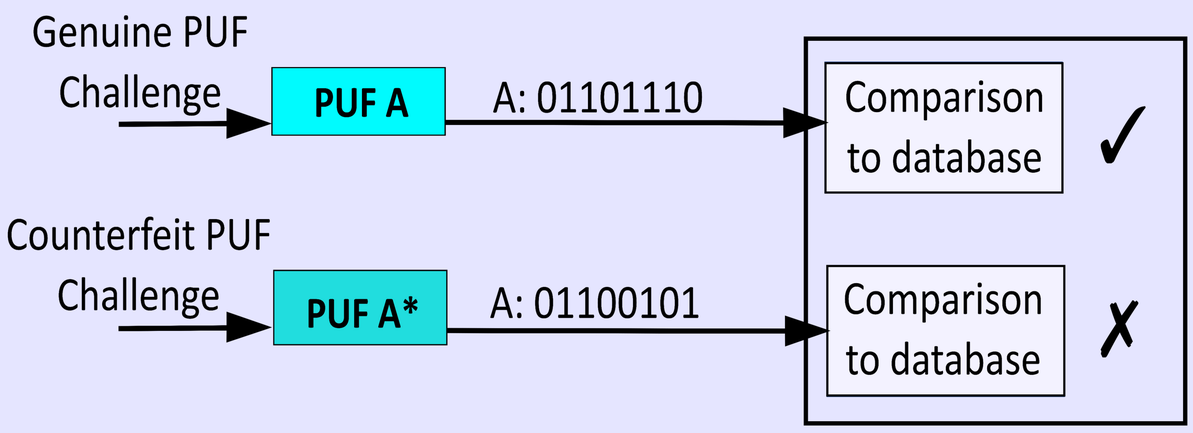
- One of the simplest quantum confinement structures
- Consists of a matrix of atoms (left), defining a quantum well (right)
- Central region is sufficiently small to form discrete energy levels (E_1)
- Energy level is very sensitive to the atomic constituents of the well



2) RTDs as Physically Unclonable Functions

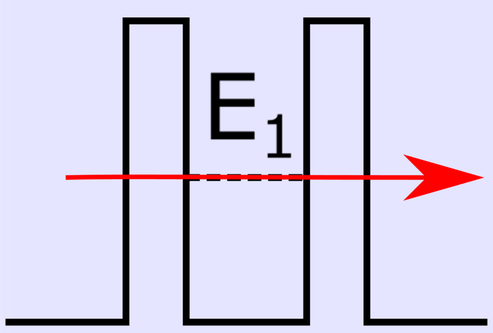
Physically Unclonable Functions (PUFs):

- Unique physical objects that cannot be recreated
- Translates an applied challenge to a unique response
- Can act as 'fingerprint' for attached circuitry or objects

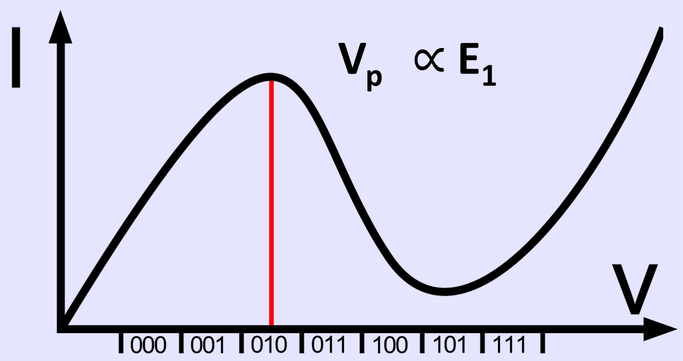


If **voltage** is controlled over RTD, we have a PUF:

- At voltage of peak (V_p), the most electrons have energy E_1
  - V_p position directly depends on energy level position E_1
  - E_1 depends on **precise atomic arrangement** in the well
- **Replication** requires characterising and fabricating the device at **atomic-level resolution** (impossible)



Band structure of RTD PUF

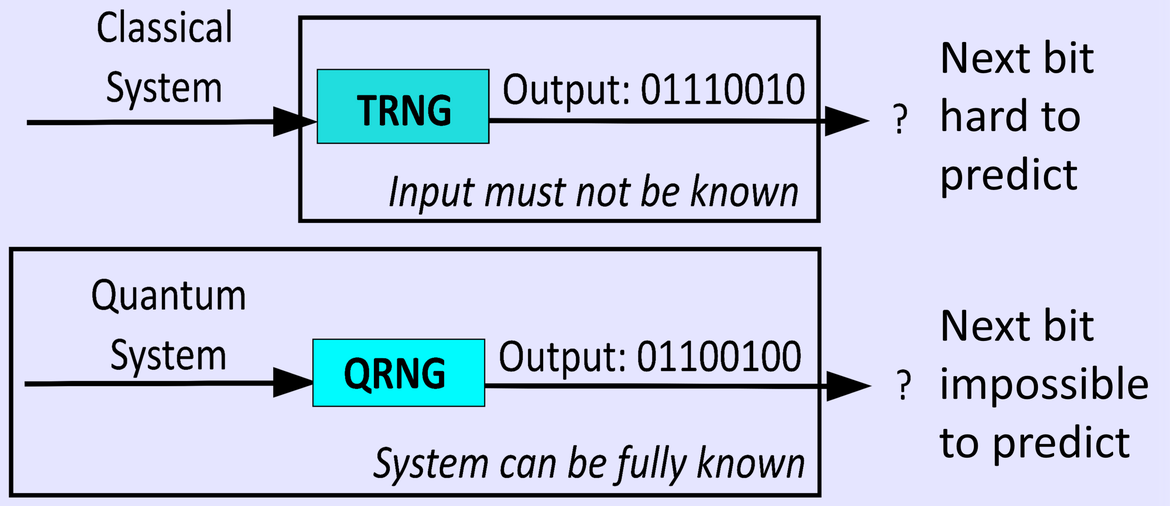


IV characteristic of RTD PUF

3) RTDs for Quantum Random Numbers

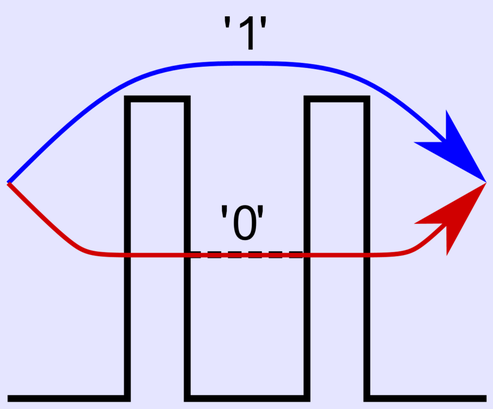
Quantum Random Number Generators (QRNGs):

- Unpredictable random number generator
- Uses quantum processes that are entirely indeterminable
- Cannot predict output, even with knowing entire system

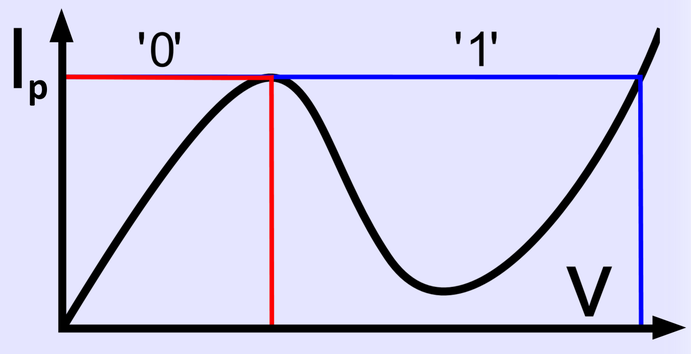


If **current** is controlled over the RTD, we have a QRNG:

- At peak current I_p, incident **electron can** pass **1 of 2 ways**:
  - **50% chance** of **tunnelling through** the barriers
  - **50% chance** of **jumping over** the barriers
- The path the electron takes is **quantum non-deterministic**, and so cannot be predicted, but can be **easily measured**

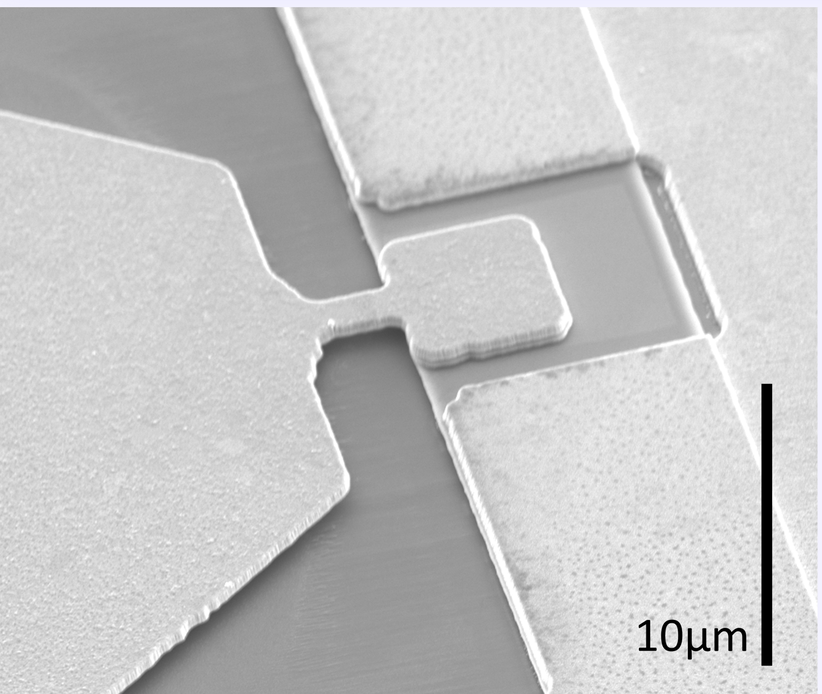


Band structure of RTD RNG



IV characteristic of RTD RNG

4) RTDs in CMOS



Typical resonant tunnelling diodes use III/V semiconductor material (Left – InGaAs/AlAs)

This material can't be directly integrated into CMOS circuit fabrication processes

Work is being done to produce RTDs in CMOS-compatible silicon (Right – Si/SiO_2)