SWTEST

PROBE TODAY, FOR TOMORROW

2022 CONFERENCE

On Shifting Defect Detection in Quantum Chips From Cryogenic to Ambient Temperature

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On Shifting Defect Detection in Quantum Chips From Cryogenic to Ambient Temperature

- Quantum computing has raised interest since 1980s
- Now quantum computing devices can be manufactured
- Devices work at cryogenic temperature (*mK*) in powerful refrigerators
- Testing at *mK* is extremely expensive
- Moving tests at higher temperatures will reduce the testing cost

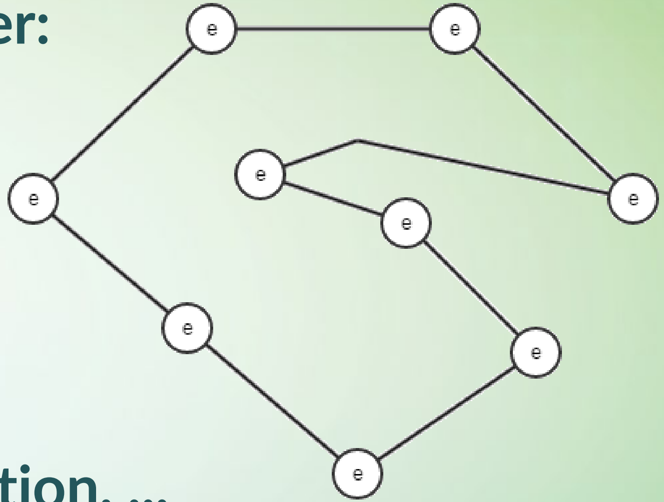
Outline

1. Introduction to Quantum Computing
2. Quantum Computing Hardware
3. Device Characterization Metrics
4. Room Temperature Measurement of Quantum Devices
5. Conclusion

1. Introduction to Quantum Computing

Quantum Computing Applications

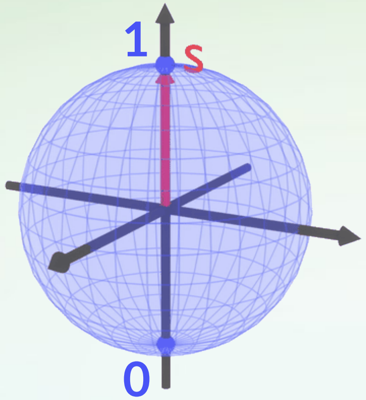
- Some problems have no efficient solution on a classical computer:
  - NP-Complete: Decision (“yes”/”no”) variants
  - NP-Hard: Optimization variants



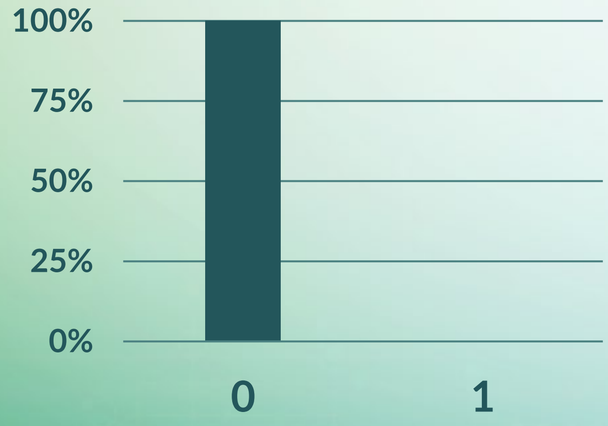
- Traveling salesman problem, maximum-2-satisfiability, factorization, ...
- Many practical applications: parcel delivery, routing of scan chain along FFs, RSA, ...
- A quantum computer can run algorithms that will drastically speed-up these problems

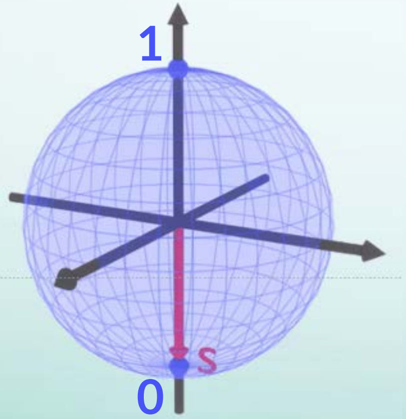
Classical vs. Quantum Computing

Classical Computing

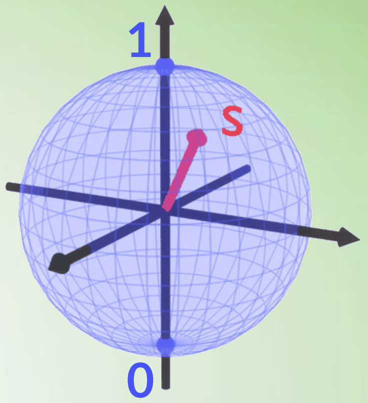


- Bit
- State either 0 or 1
- State known with certainty in fault-free system

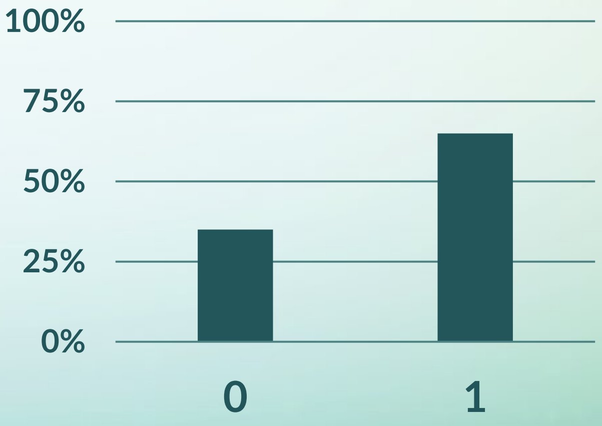


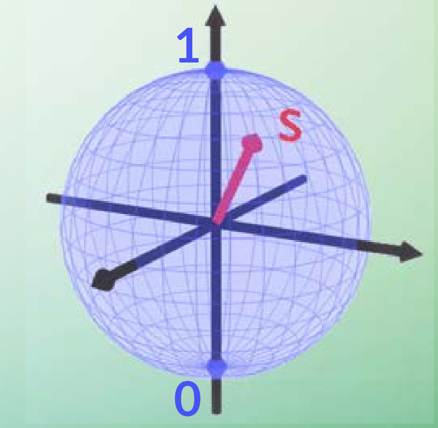


Quantum Computing



- Qubit
- Superposition of states 0 and 1
- Probability of measuring 0 or 1

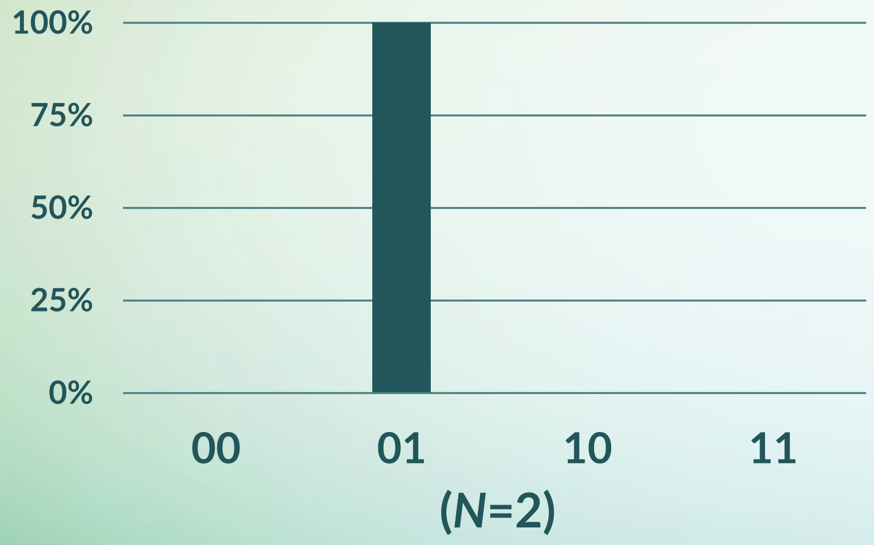




Classical vs. Quantum Computing

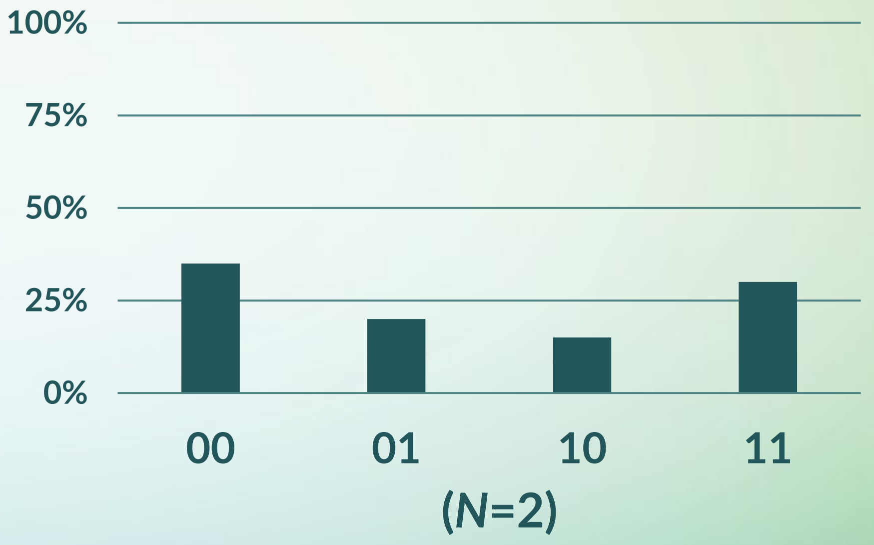
Classical Computing

- *N* bits in one out of 2^N states



Quantum Computing

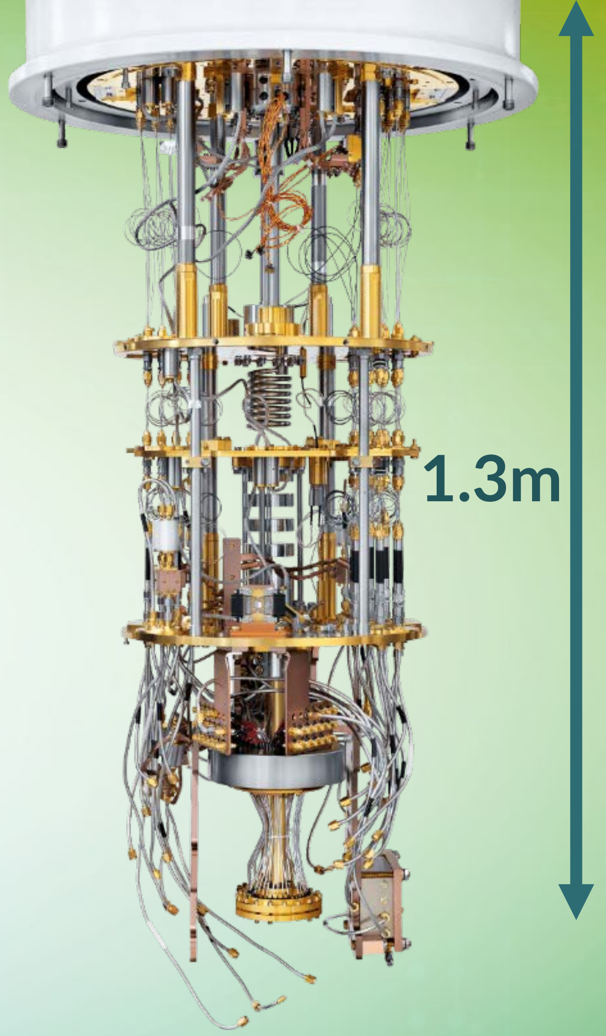
- *N* qubits in superposition of 2^N states



A quantum computer can process all 2^N states at the same time

Quantum Computing as a Service

- Quantum computers not expected to become a commodity
  - Require operation at cryogenic temperature
  - Expensive, bulky equipment
- Quantum computing
  - Will be based on shared computing resources (“cloud”)
  - No high-volume testing necessary
  - Only targets specific classes of problems

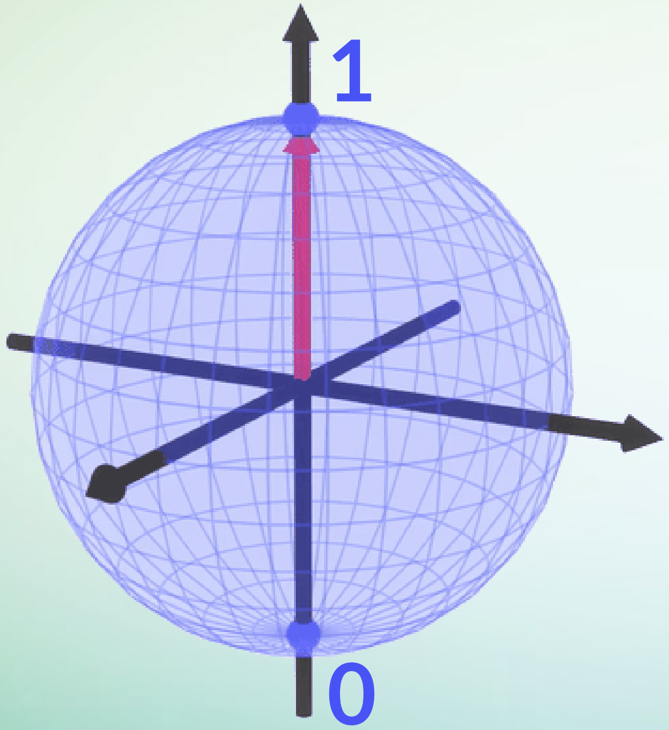


- A quantum computer is not universally better than a classical computer

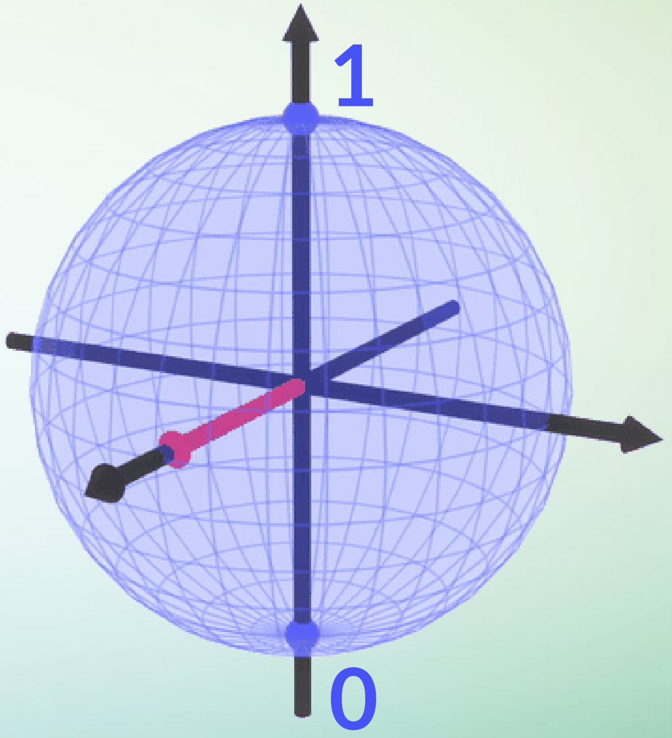
2. Quantum Computing Hardware

Qubit Non-Idealities

- Real qubits are not stable



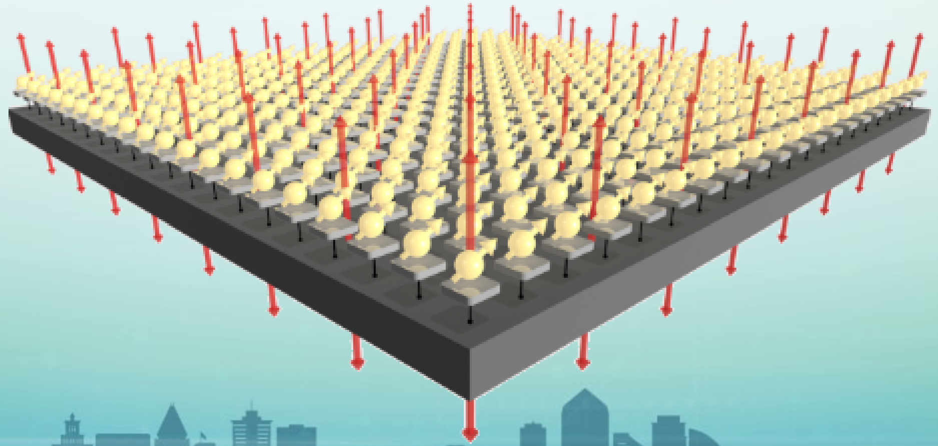
Relaxation



Dephasing

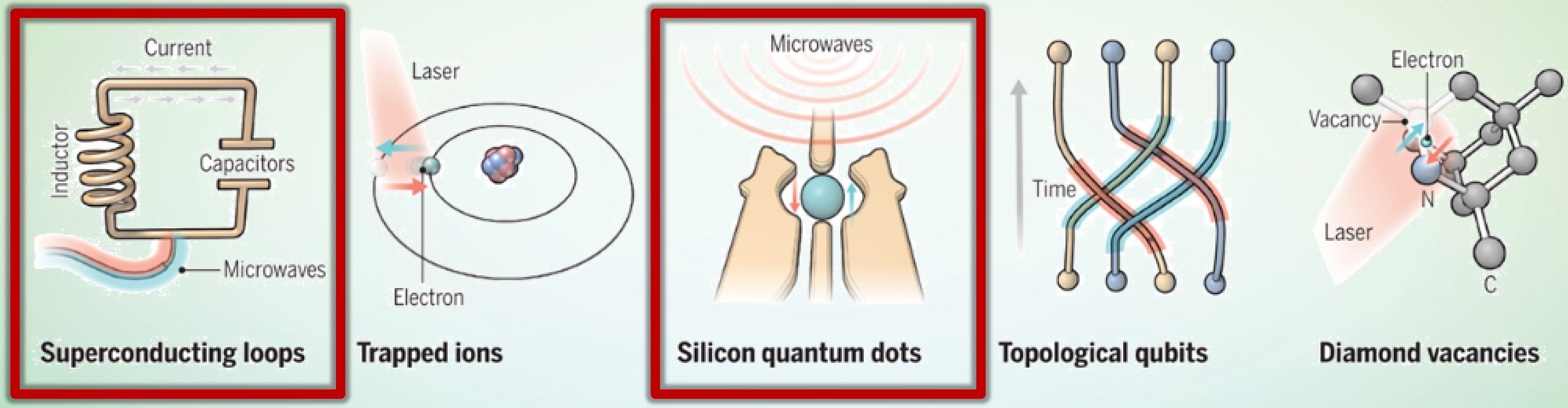
Real Problems Require Large-Scale Quantum Computers

- Solving complex problems → 10^3 stable logical qubits
- Single logical qubit → 10^3 redundant physical qubits
- Fault-tolerant large-scale quantum computer → 10^6 physical qubits



Quantum Computing Platforms

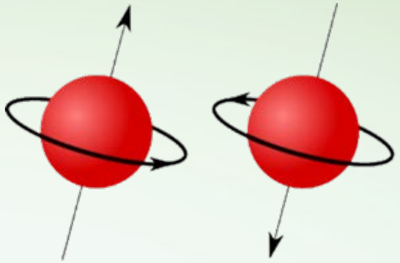
- Quantum computing theory has been known for many years
- Recently: focus on building quantum computing devices



- At imec:
  1. Superconducting
  2. Silicon quantum dots
- Operation at *mK* in $^3He/^4He$ dilution refrigerator

Silicon Spin Qubits

- ***Qubit:***
  Spin of a single electron in silicon



- ***Quantum dot:***
  Area where the electron is confined

- ***Qubit manipulation:***
  Microwave pulses with ESR antenna

- ***Qubit readout:***
  Single Electron Transistor

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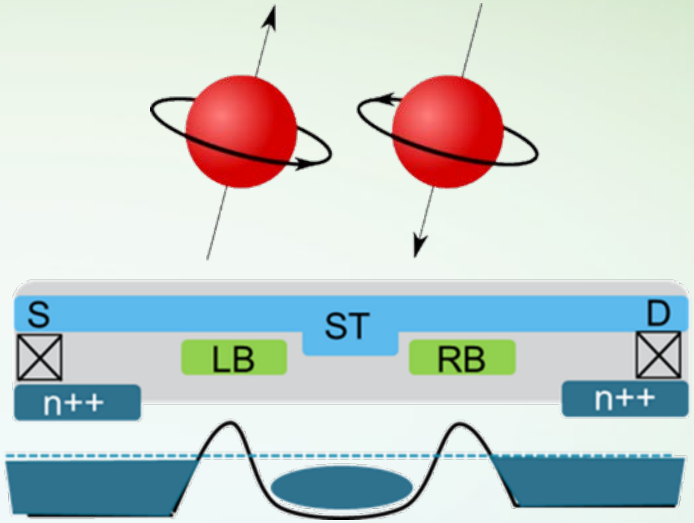

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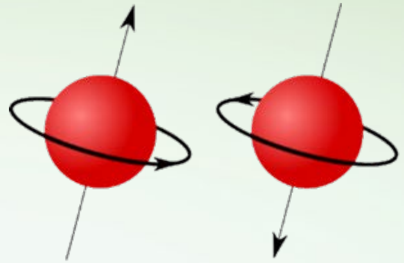

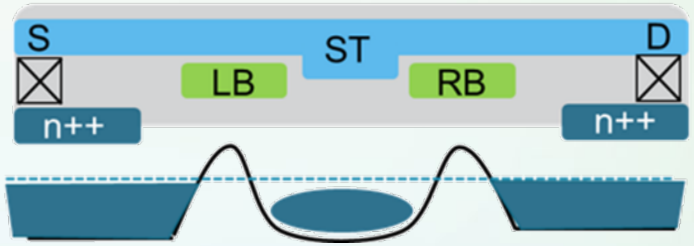

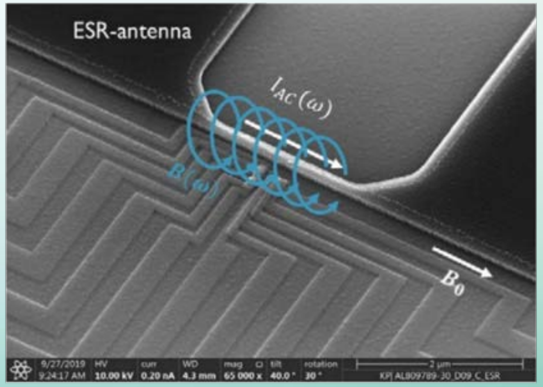

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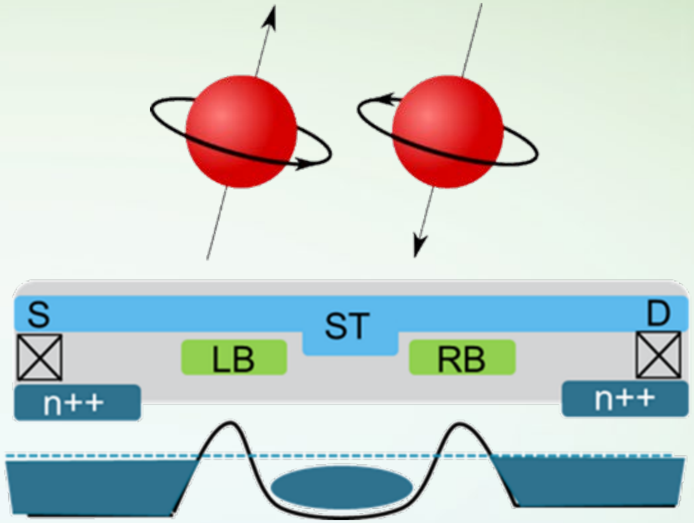

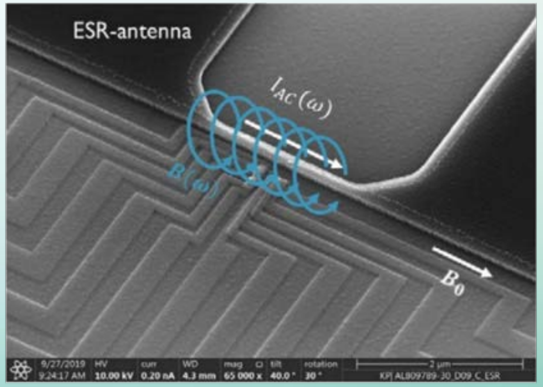

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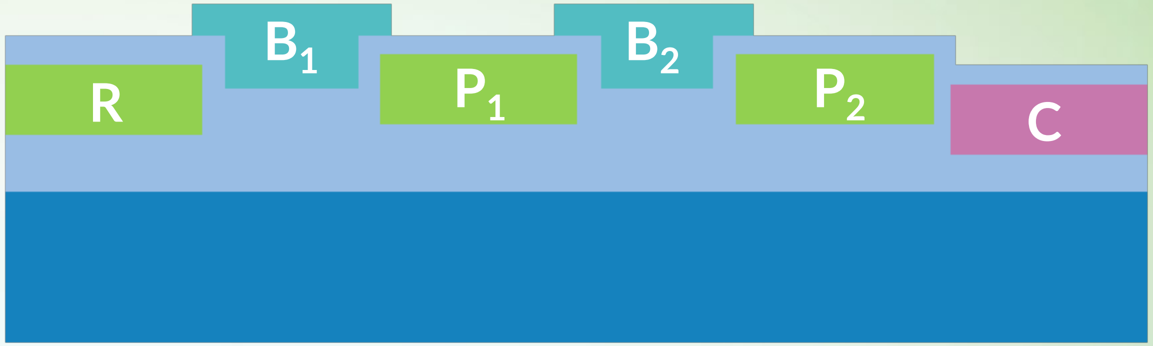
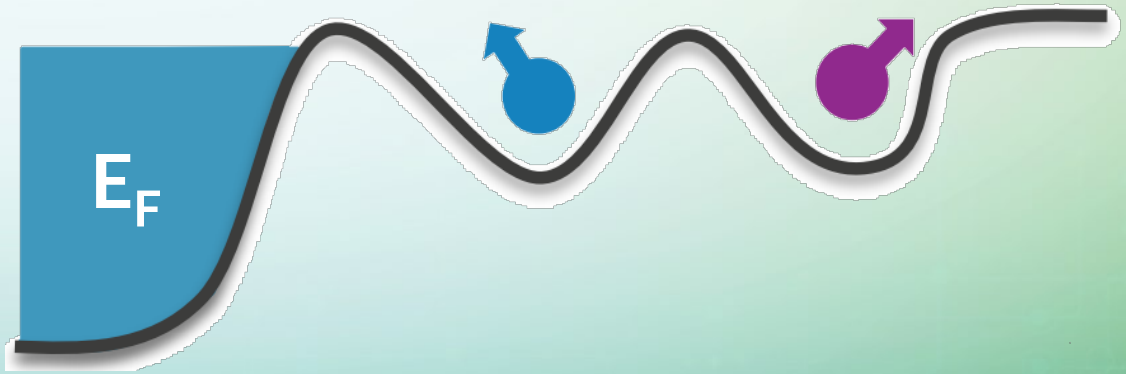
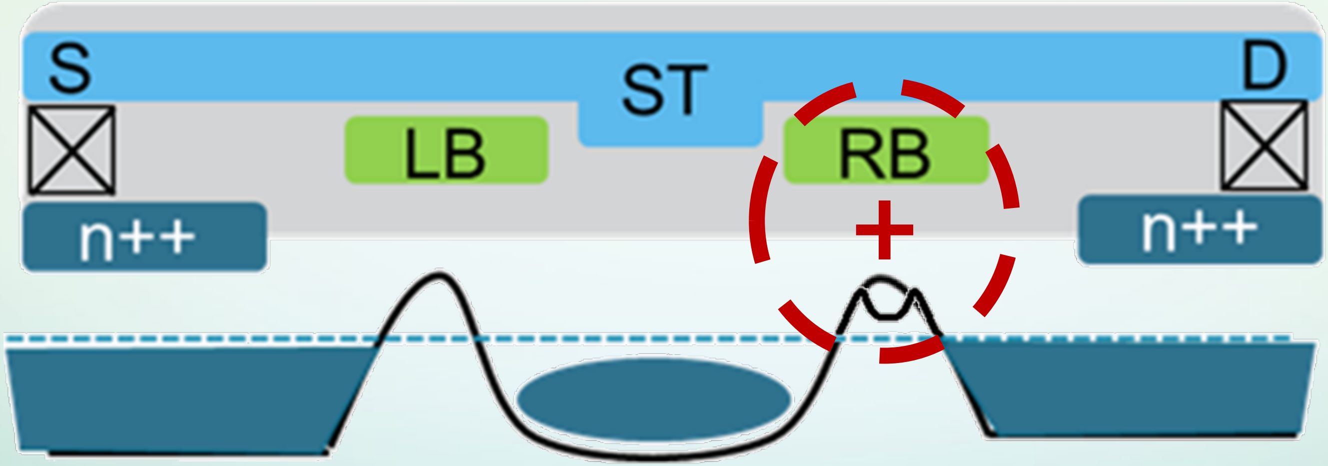




3. Device Characterization Metrics

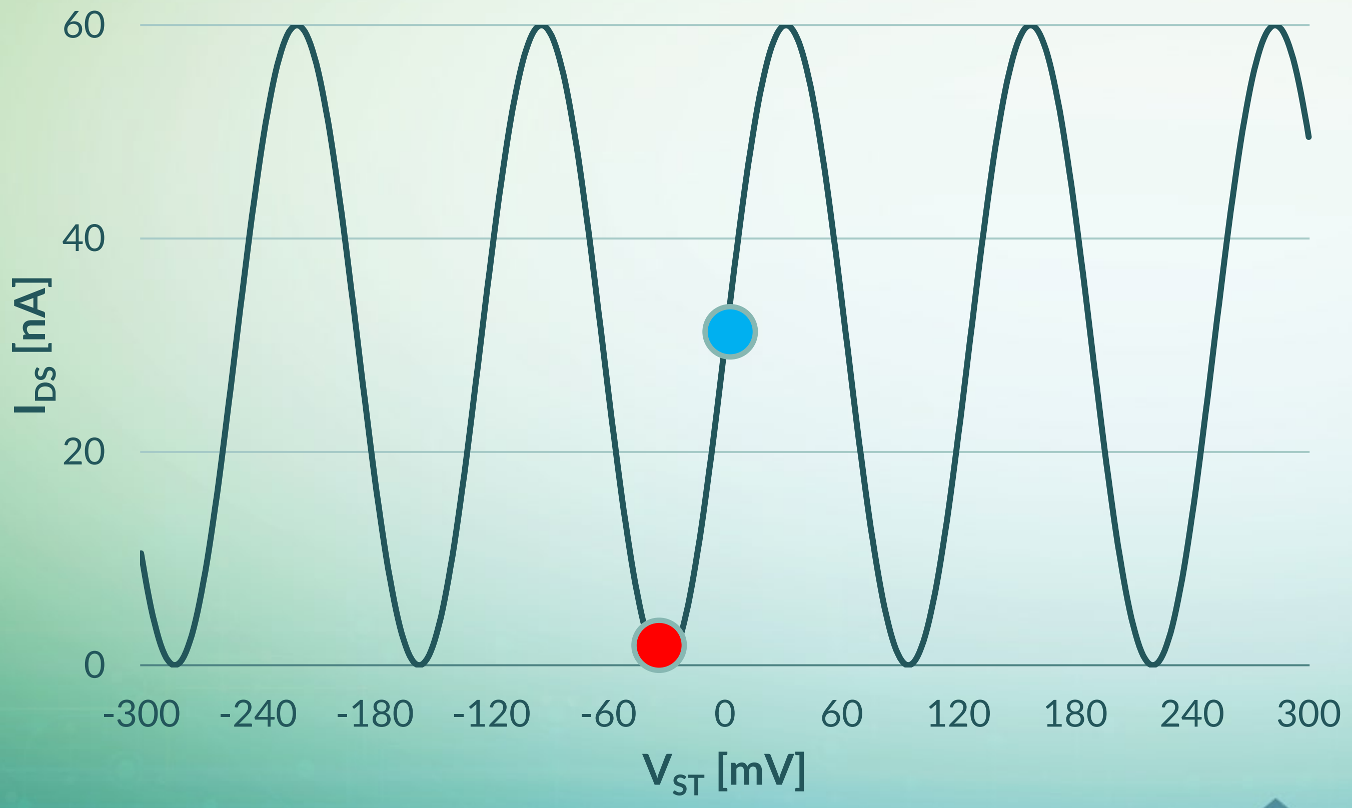
Interface Disorder Main Limiting Factor

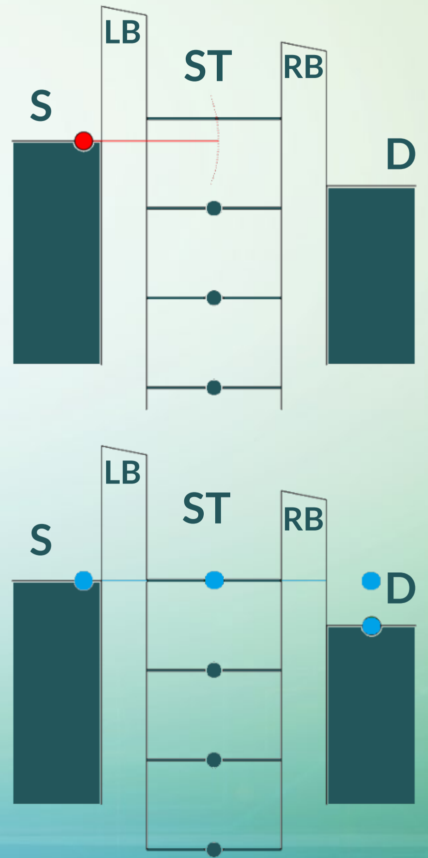
- Main source of noise: Si/SiO_2 interface disorder



Coulomb Blockade Effect

- **Interface disorder characterized with quantum dot metrics**
- **Working principle: Coulomb blockade effect at *mK***





Limits of Quantum Dot Metrics

- Based on Coulomb blockade effect at *mK*
- Measurement in ${}^3He/{}^4He$ dilution refrigerator
  - Long cooldown times (~12h)
  - Contains few devices
  - Expensive equipment

From Quantum Dot to Transistor Metrics

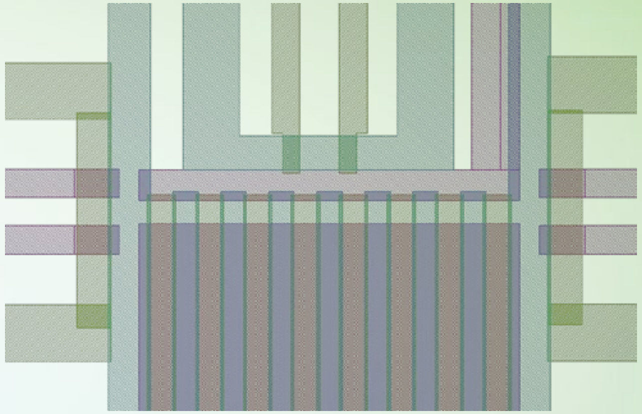
	295K	4K	40mK
Transistor Metrics			
V_{th}	✓	✓	✓
SS	✓	✓	✓
g_{max}	✓	✓	✓
Quantum Dot Metrics			
Charge Drift		✓	✓
Mobility		✓	✓
Barrier Maps			✓
Coulomb Diamonds			✓
Qubit Metrics			
Relaxation Time			✓
Coherence Time			✓
Single Qubit Gate Fidelity			✓
Two Qubit Gate Fidelity			✓

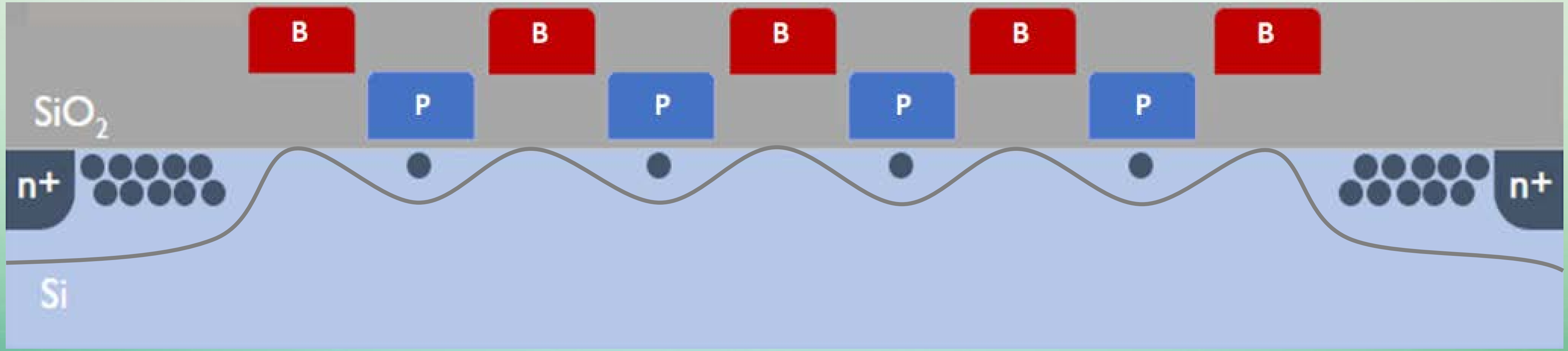
- Measurement at higher temperatures
  - No dilution refrigerator needed
  - Reduce long cooldown times by 87%
  - Measure 30× devices
- Cryogenic wafer probers at 4K

4. Room Temperature Measurement of Quantum Devices

Room Temperature Measurement of Quantum Devices

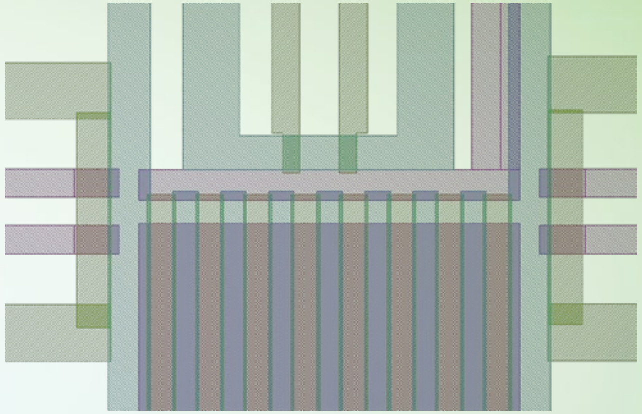
- Measurement of long quantum dot arrays
  - Multiple gates on multiple gate levels
  - From 3 up to 8 quantum dots

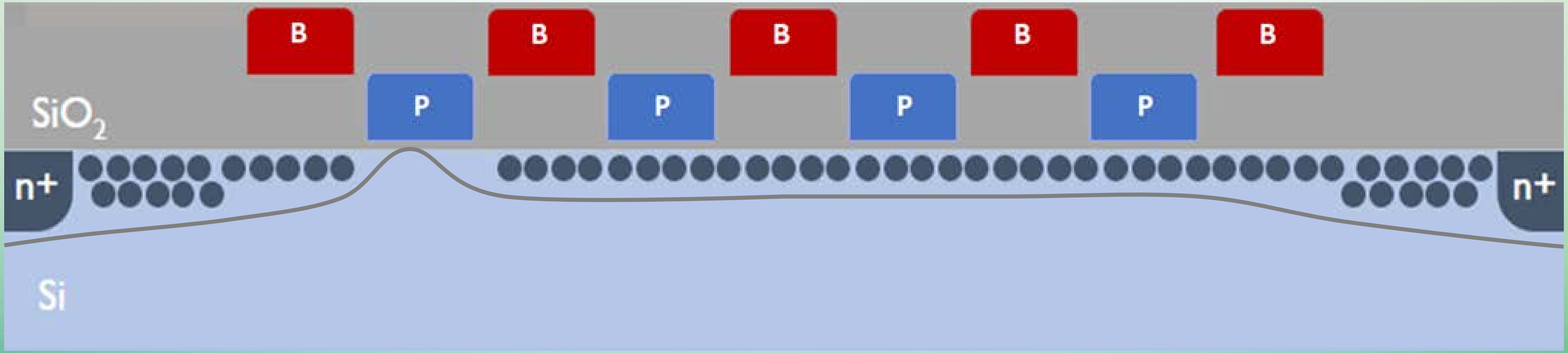




Room Temperature Measurement of Quantum Devices

- Transistors with multiple gates
- Statistical analysis of V_{th}, SS, g_{max}
- I_dV_g curves extracted for each individual gate





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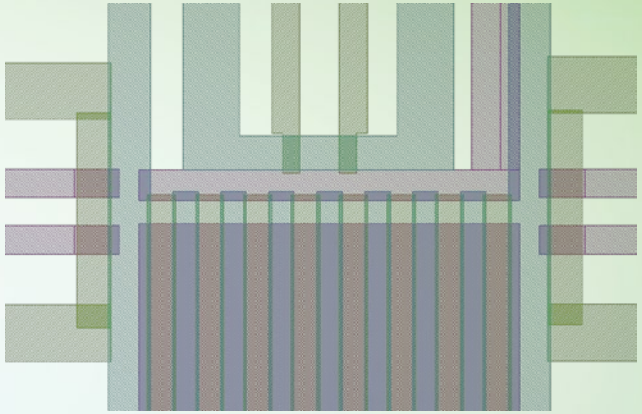

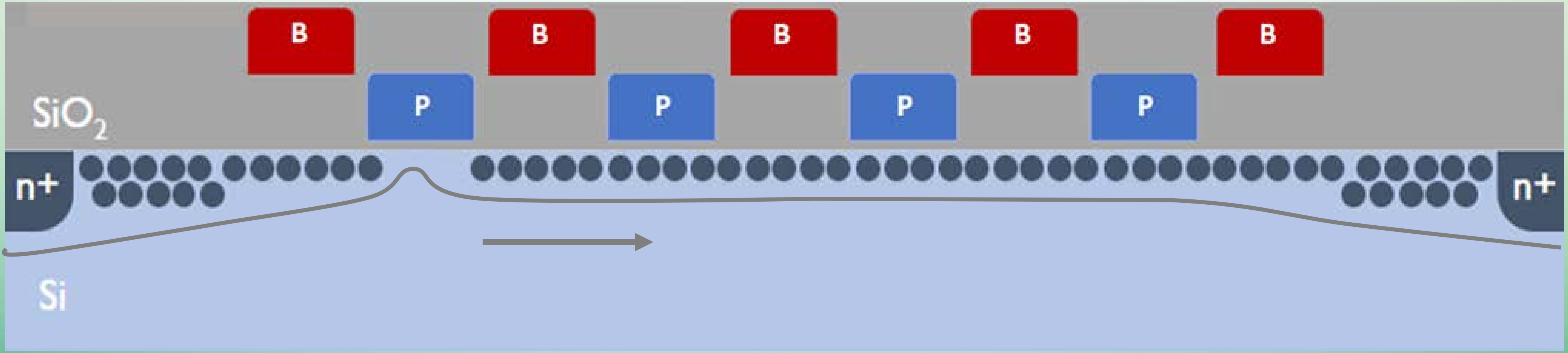

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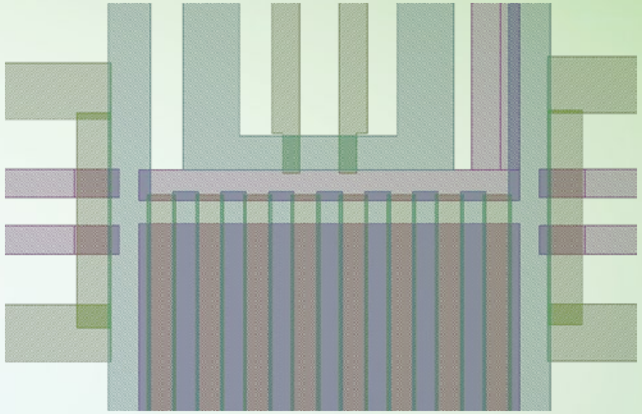

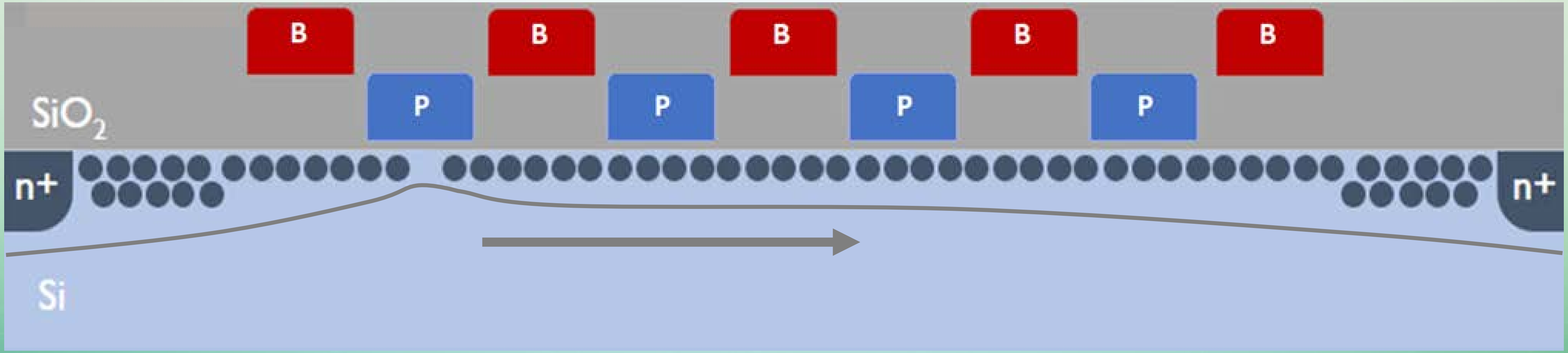

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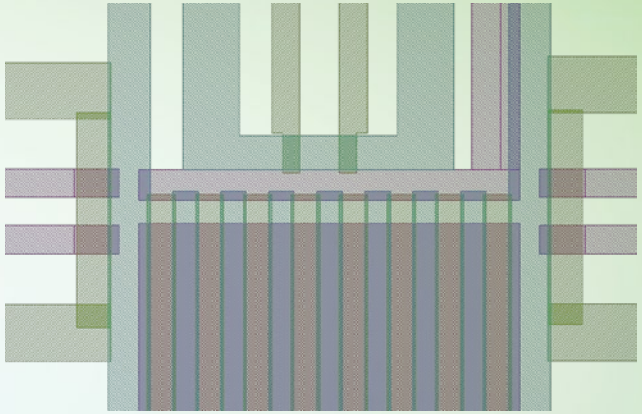

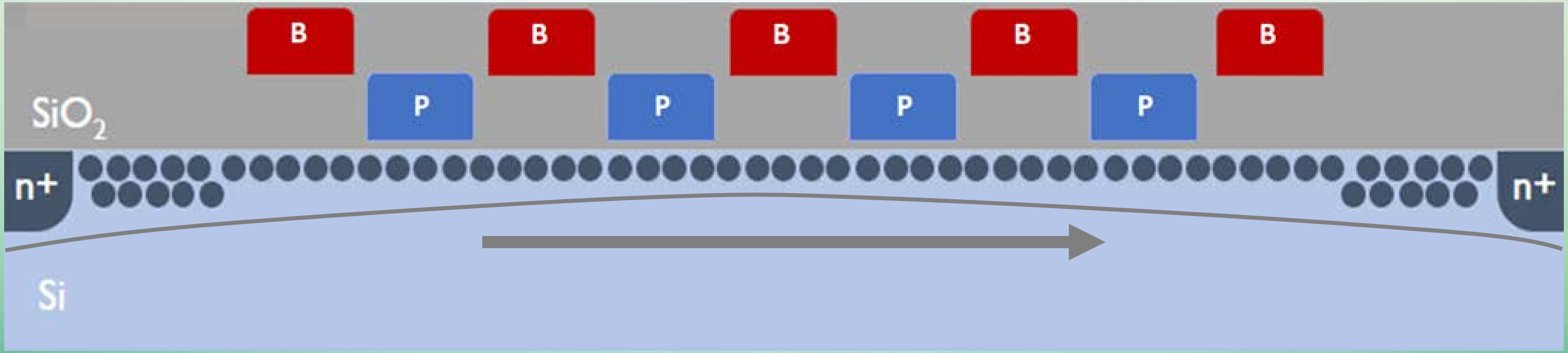

Conclusion

- Quantum computers will speed-up classically intractable problems
- Silicon spin qubits are a promising platform
- Si/SiO_2 interface disorder is the main limiting factor for Si spin qubit devices
- Interface disorder mainly characterized with quantum dot metrics at *mK*
- Transistor metrics can be used for interface quality assessment at *T* higher than *mK*
- Testing more devices with shorter cooldown times to reduce testing cost
- Currently investigating interface disorder of test structures through transistor metrics