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CIQTEK

Quantum Computer For Education

Diamond I

Global Quantum Technology Programming

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UK, 2014	UK National Quantum Technologies Programme
USA, 2016	National Quantum Initiative Act
China, 2016	National Quantum Scheme
Germany, 2018	Quantum Technology-From Basics Research to Market
Netherland, 2019	Quantum Delta NL
Canada, 2020	Quantum Industry Canada
Korea, 2020	Five-year Development Program for Quantum Computing Technology
France, 2021	France’s quantum strategy
Austria, 2021	Quantum Austria
Japan, 2022	Quantum Strategic Industry Alliance

Quantum Computing: From Theory to Experiment

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Urgent need for a large number of quantum relevant professionals

Building quantum technology science,
Cultivating Quantum Technology Talents

A complete quantum computing system

Promote the construction of quantum mechanics,
Innovative the teaching methods

Provide the fundamental for quantum computing research

Combining theory and experiment,
Improve students' interest of learning

Learn the cutting-edge knowledge and technology of quantum computing

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Diamond Quantum Computer For Education
Diamond I

Diamond Quantum Computer for Education is based on the principle of NV color center and spin magnetic resonance in diamond. By controlling laser, microwave, magnetic field, etc, to perform quantum manipulation and readout of the spin of the NV color center to realize the quantum computing functions.

Characteristic & Feature

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Characteristic

- The world's first quantum computing for education
- Tabletop devices that operate at room temperature & atmospheric conditions
- Zero running costs
- Modular design and rich teaching functions
- A truly qubit quantum computer
- Provide supporting teaching course solutions

Feature

Brand	**CIQTEK**
Model	Diamond I
Certificate of orignal	China
Laser power	10 mW
Laser wavelength	520 nm
Switch ratio	> 30 dB
Fluorescence collection	650 - 800 nm
microwave power	< 16 W
microwave channel	2
microwave frequency	2 - 3.5 GHz
Magnetic field range	10 - 50 Gauss
Time control accuracy	2 ns
Pulse width range	2.0 ns - 2.5 s
number of pulses	25000 (typical)

Instrument principle

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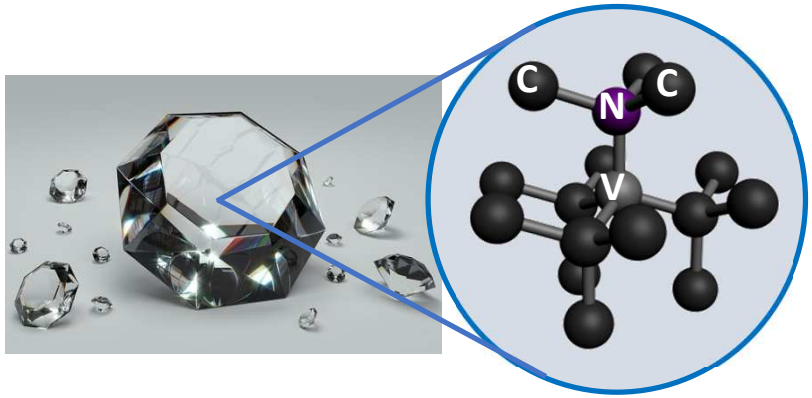
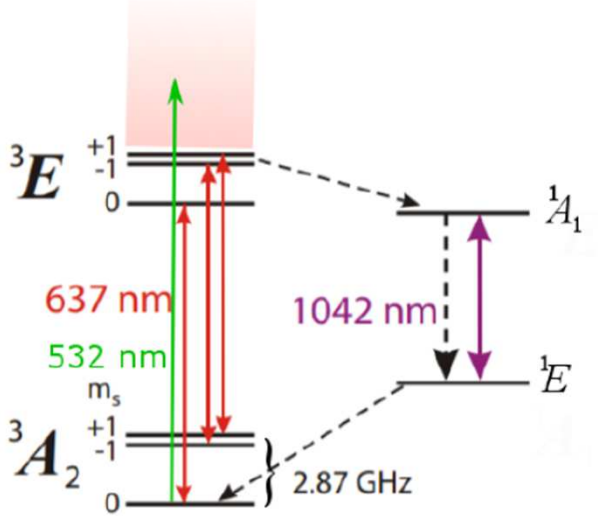
Qubit



The NV color center is composed of a substituted nitrogen (Nitrogen) and an adjacent vacancy (Vacancy), which is a paramagnetic defect center

Initial state preparation



Three energy levels system, $|m_s = 0\rangle$, $|m_s = +1\rangle$ and $|m_s = -1\rangle$ can be regarded as qubits

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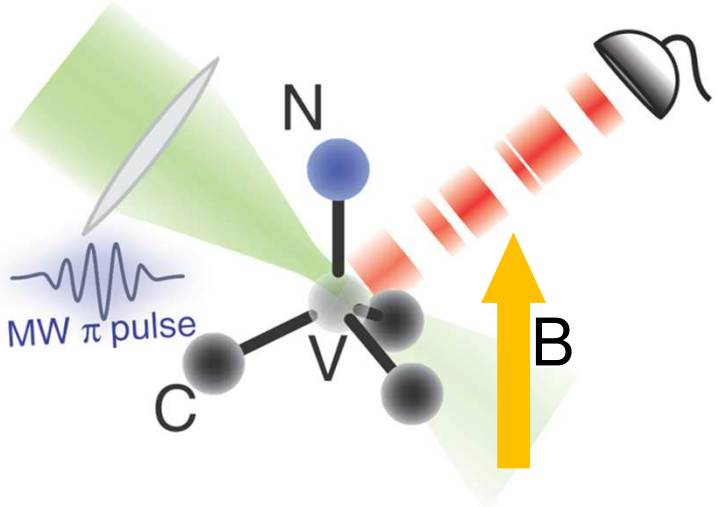
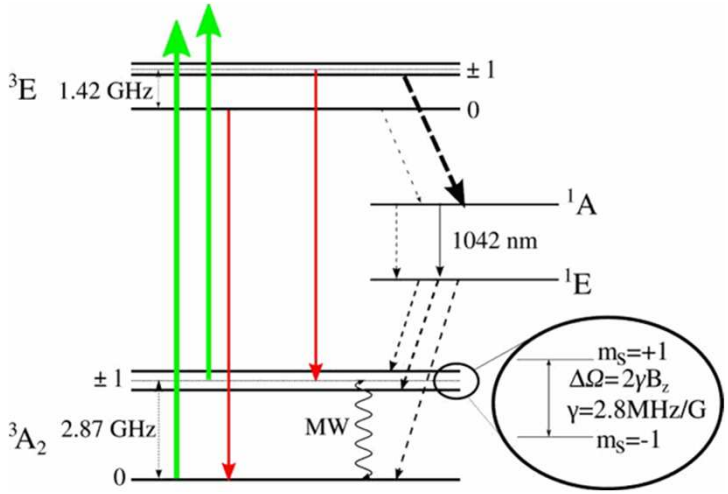
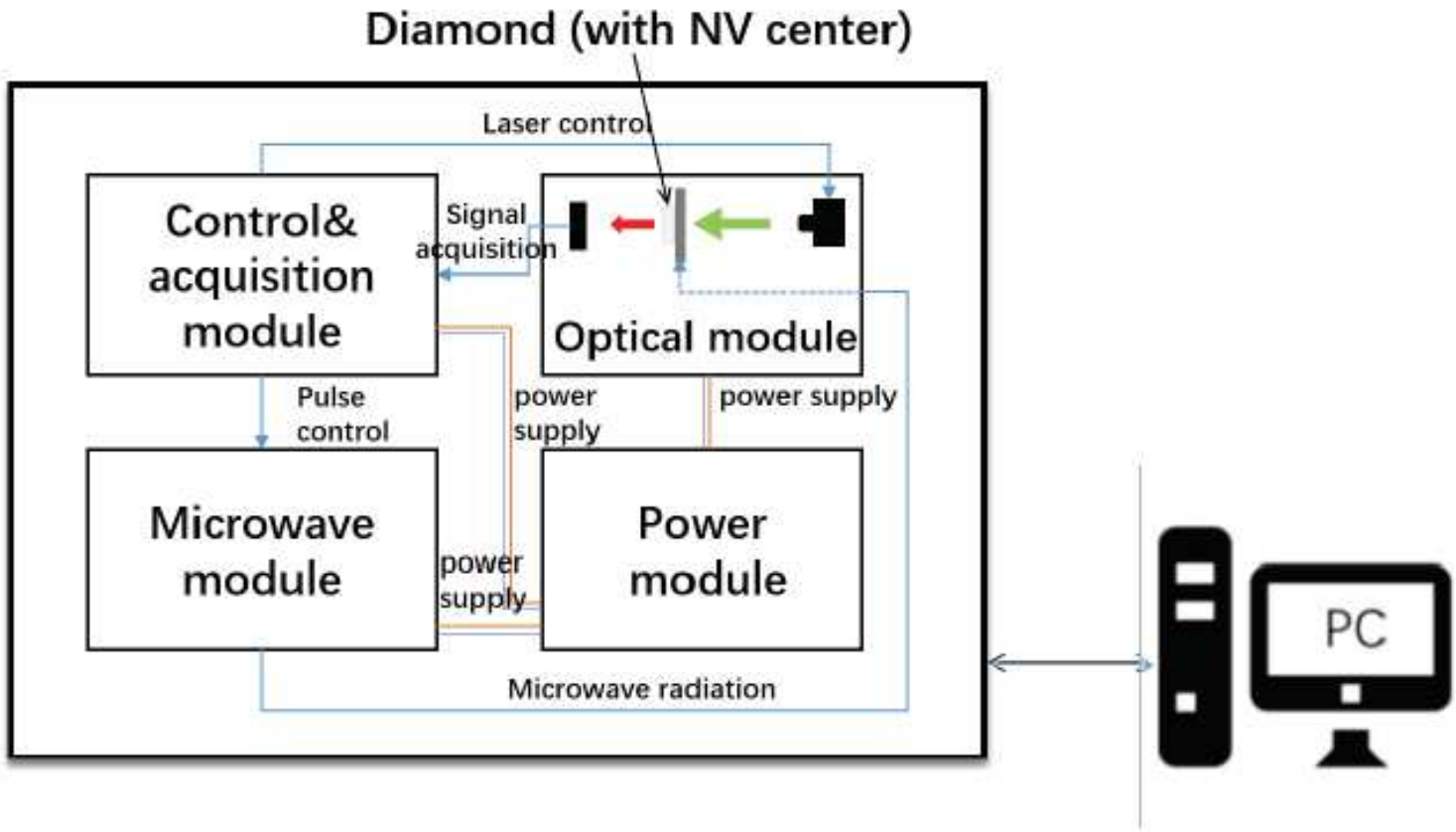
Quantum manipulation



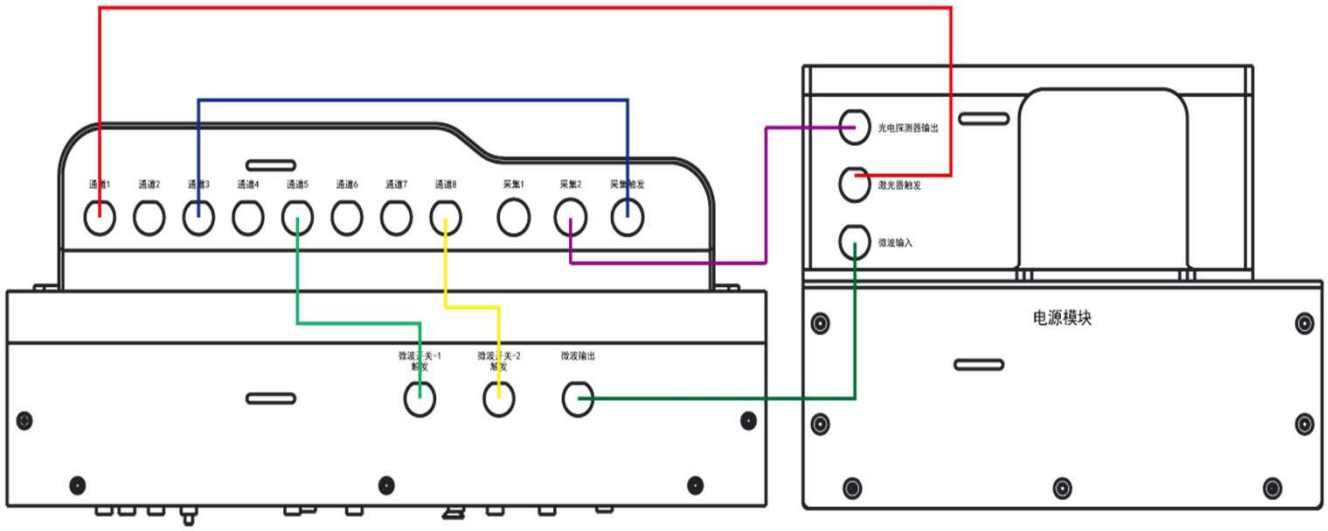


By applying and controlling lasers, microwaves, and magnetic fields, the NV color center spin state is fluorescently detected, quantum manipulation and readout are realized, and the basic functions of quantum computing.

Instrument structure



Instrument structure



- CH1-Laser trigger
- CH3-Acquisition trigger
- CH5-Microwave CH1 trigger
- CH8-Microwave CH2 trigger
- Microwave output-input
- Acquisition2-PD output

Instrument function

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Quantum Computing

- Qubits
- Quantum logic gate
- Quantum decoherence
- Quantum algorithm

Quantum Mechanics

- Quantum state
- quantum state evolution
- Zeeman effect
- Electron spin

More Functions

- Magnetic resonance
- ODMR
- Quantum control
- Quantum measurement

Experiment content and course plan

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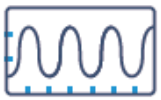
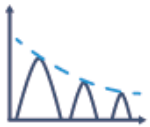
Instrument Calibration

Set up and adjust the instrument, get familiar with the principle of optically detected magnetic resonance, NV center, microwave generation and pulse control.



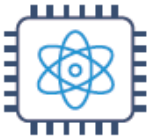
Rabi Oscillation

The Rabi oscillation of NV center is measured, and get the microwave pulse length corresponding to the quantum logic gate.



T2 Measurement

T2 experiment shows the evolution of quantum superposition state and measures the decoherence time of NV center spin.



D.J. Algorithm

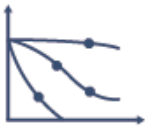
A two-qubit Deutsch-Jozsa quantum algorithm is realized on the NV center quantum processor.

Continuous Wave

Understand NV center qubit by measuring the optically detected magnetic resonance spectrum and get the resonance frequency for spin control.

Spin Echo

Spin echo is an effective technique used to suppress the coupling between the qubit and the environment, so as to prolong the coherence time.



Dynamic Decoupling

The decoherence time is extended by designing the dynamic decoupling sequence to average out the coupling between the qubit and the environment.

Software interface

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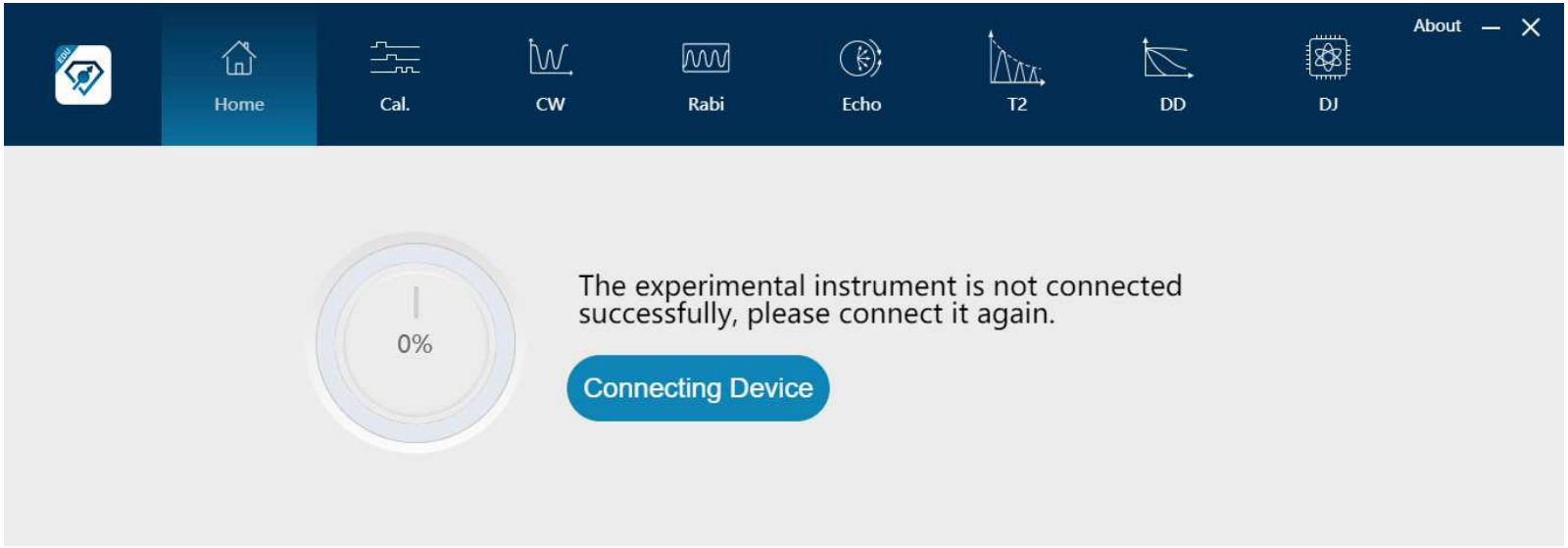
Diamond I Studio



Calibration experiment

Experimental purpose

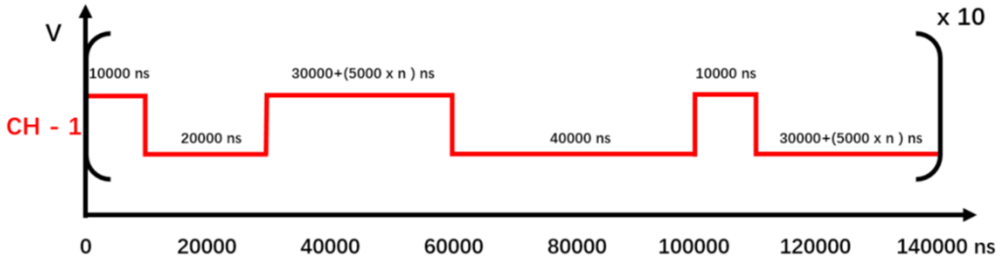
Through the construction, connection and parameter adjustment of the instrument modules, familiar with the functions and signal control of different modules of the instrument, and understand the experimental principle. and learn to write pulse sequences by experimenting with arbitrary sequences.

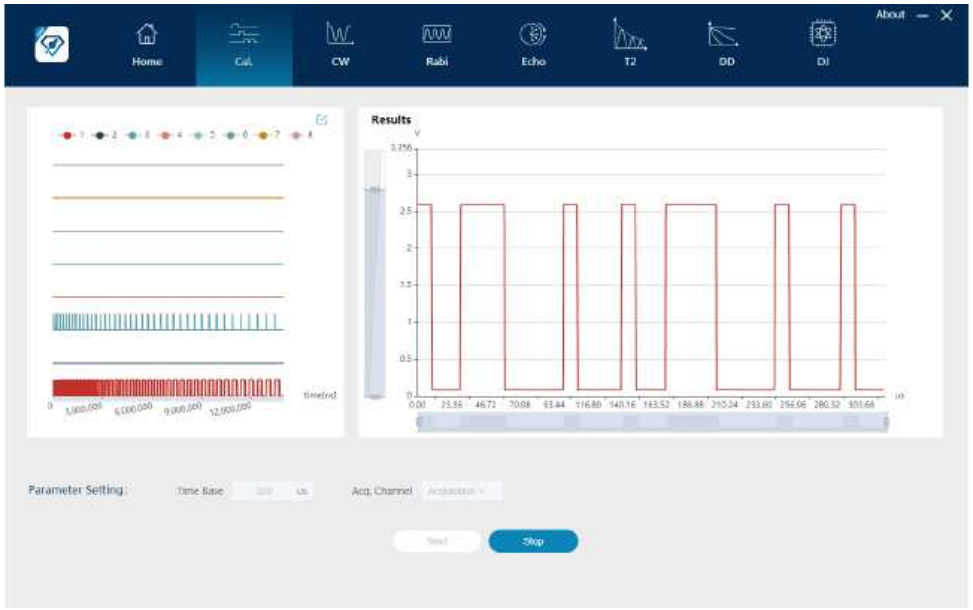
Contents：

① Instrument module connection

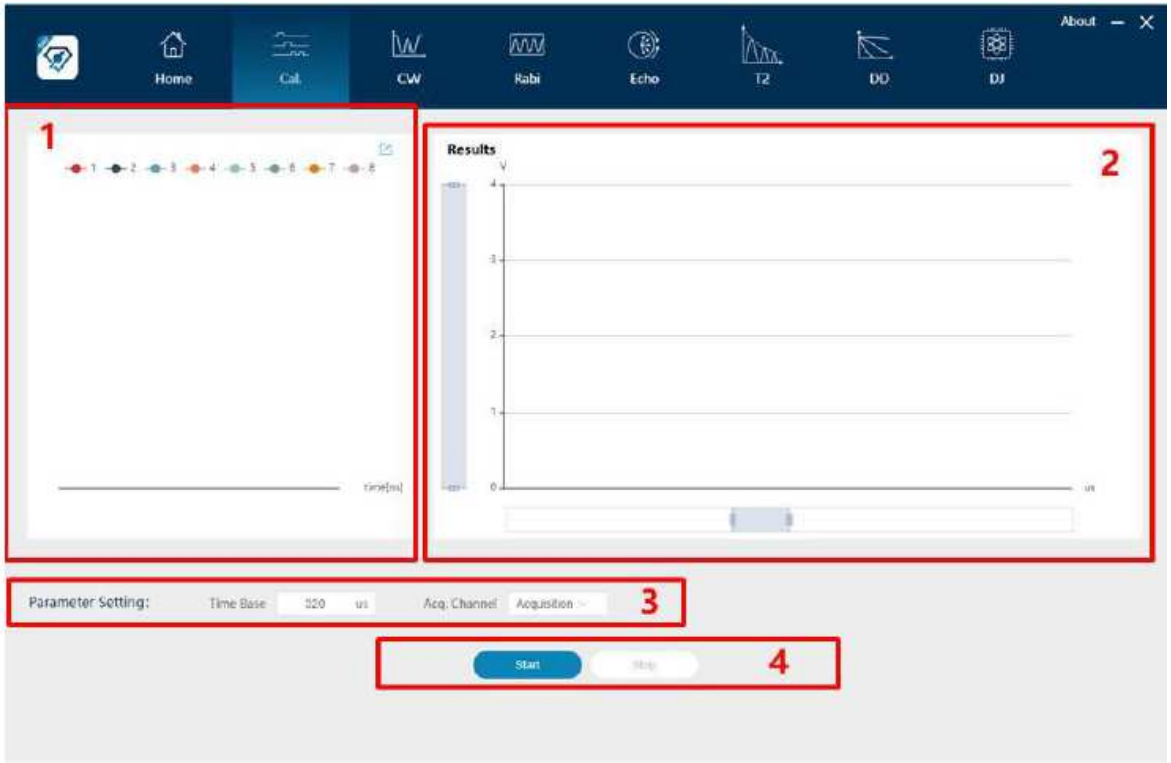
② Arbitrary sequence experiments

③ Optical path adjustment experiment





Calibration experiment



① Area 1 is the preview area of the pulse sequence

② Area 2 is the waveform area of the Calibration Experiment output. If the color of the box is green, it means that the channel outputs a high level within the defined length and step time, otherwise it is a low level

③ Area 3 is the parameter configuration area of the experiment

④ Area 4 is the control area of the experiment

Continue wave experiment

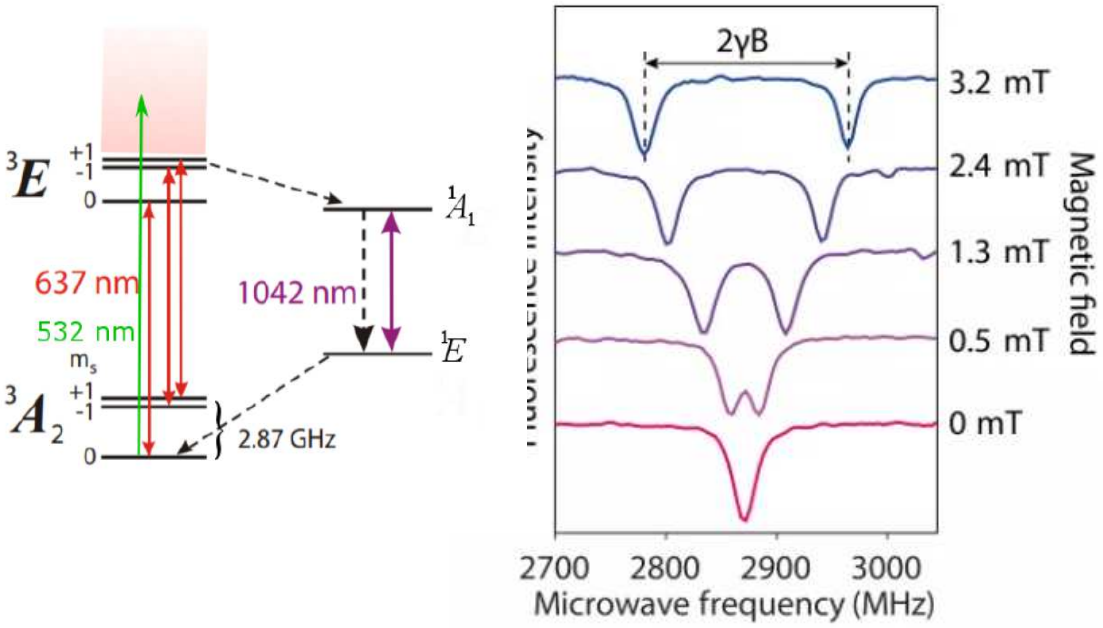
Experimental purpose

① Observe and understand the Zeeman effect

② Understand NV center energy levels and qubits

③ Readout of the spin state of the NV color center

Experimental principle



NV Color Center Energy Level Structure and Zeeman Effect

Continue wave experiment

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Experimental results

Experimental summary

① The spin state of the NV color center can be initialized by the laser, and the brightness of the resulting fluorescence depends on spin state

② Imposing microwave to the NV center, when the microwave frequency equal to the resonates frequency of the energy level interval, it can change the population of the spins state in the |0> and |±1> , thereby changing the fluorescence intensity, and there will be a trough on the spectral line

③ According to the Zeeman effect, the difference between the frequencies corresponding to the two troughs is proportional to the magnitude of the external magnetic field

Rabi oscillation experiment

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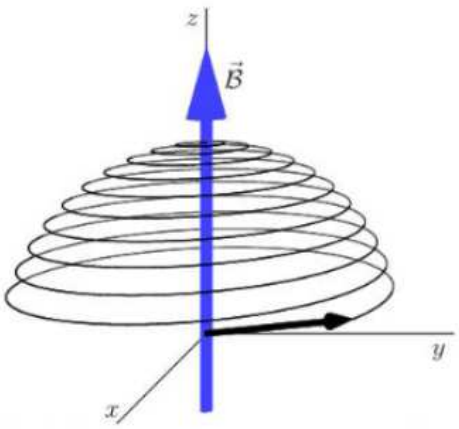
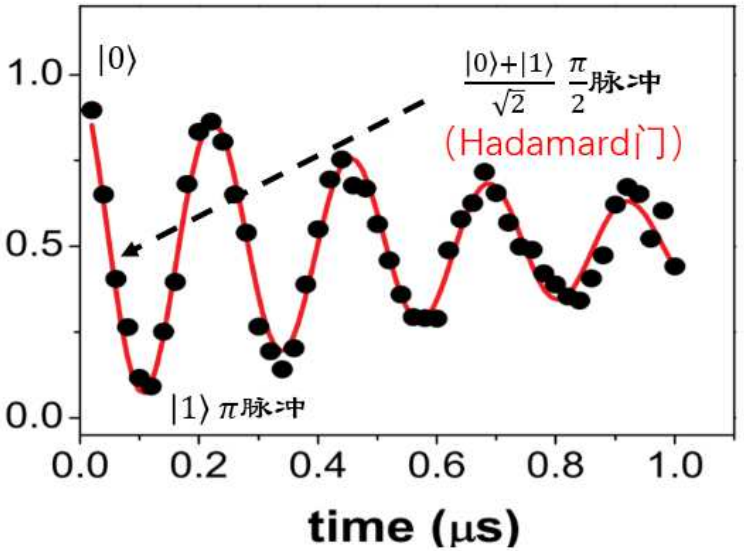
Experimental purpose

① Observe and understand the phenomenon of Rabi oscillation

② Understand the principle of quantum state manipulation, which under the microwave resonant frequency, the state of the qubit can be manipulated by changing the duration of the microwave pulse

Experimental principle





Rabi oscillation experiment

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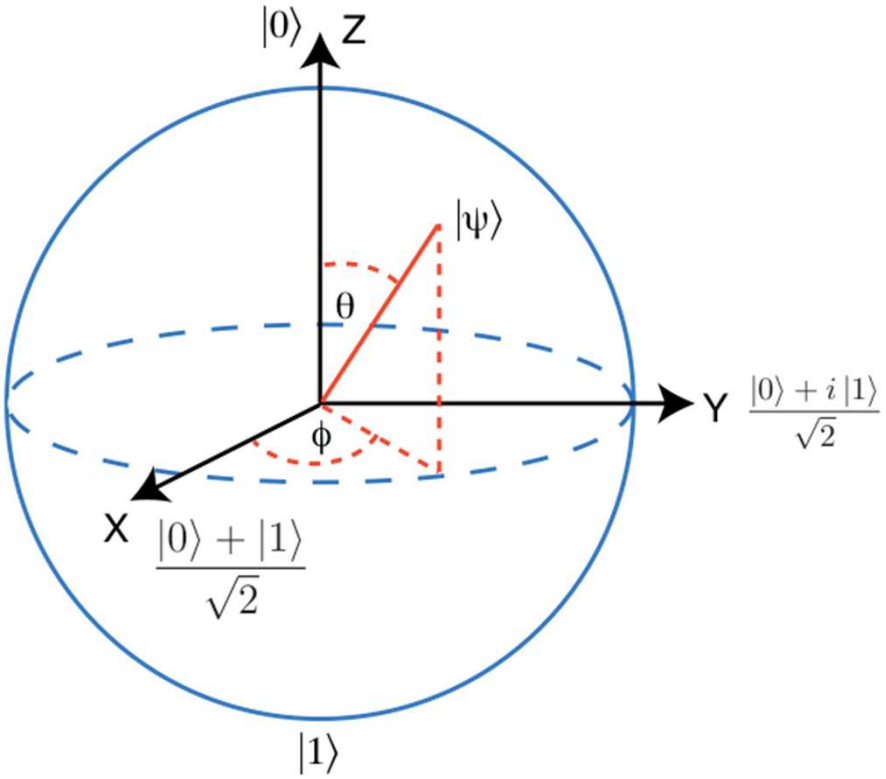
Experimental results

Experimental summary

① The Rabi oscillation experiment measures the Rabi oscillation curve of the NV color center driven by microwave, and is used to determine the microwave pulse width corresponding to the operation of the quantum logic gate

② Fixing the microwave frequency as the resonant frequency, increasing the microwave duration, the spin state is periodically reversed between the |0> and the |-1> or the |0> and the |+1>, oscillating curve can be observed, then, the spin state can be determined according to the oscillation period, and the spin operation can be performed by microwaves corresponding to the pulse width.

Bloch sphere



The Bloch sphere is an efficient method for the visual representation of a single-bit state, that is, a state vector is represented by a point on a sphere with unit radius.

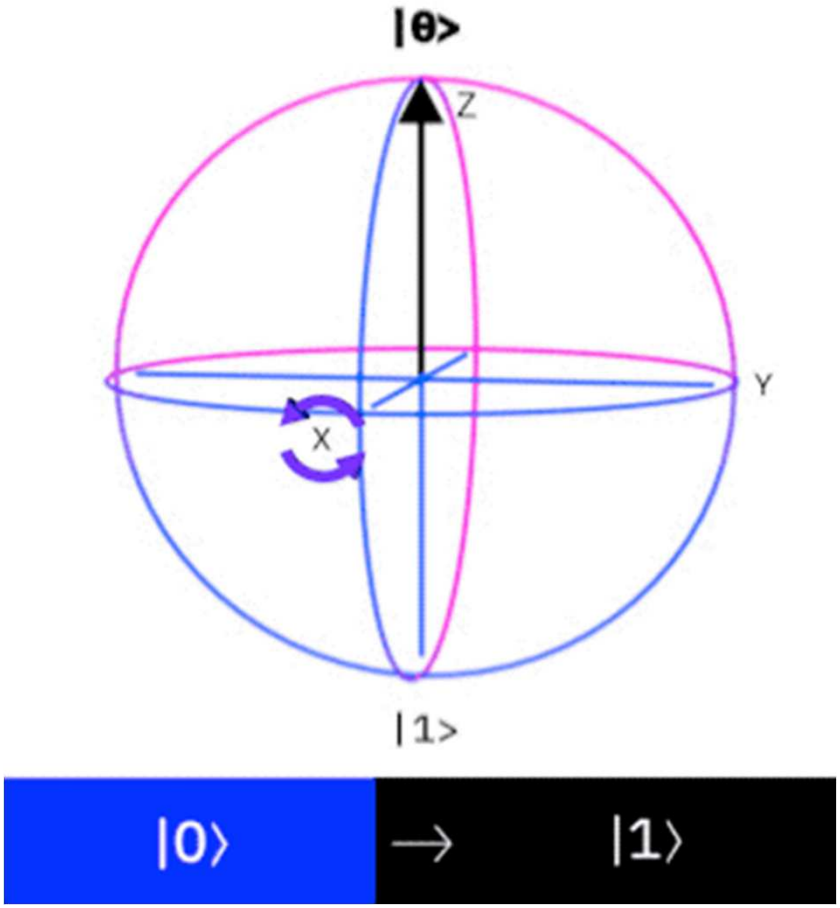
3D Cartesian Coordinates:

$$\boldsymbol{x = cos\phi sin\theta, y = sin\phi sin\theta, z = cos\theta,}$$

$$\boldsymbol{|\psi\rangle = cos\frac{\theta}{2}|0\rangle + e^{i\phi}sin\frac{\theta}{2}|1\rangle,}$$

$$\boldsymbol{\theta \in [0, \pi], \phi \in [0, 2\pi].}$$

Pauli X logic gate

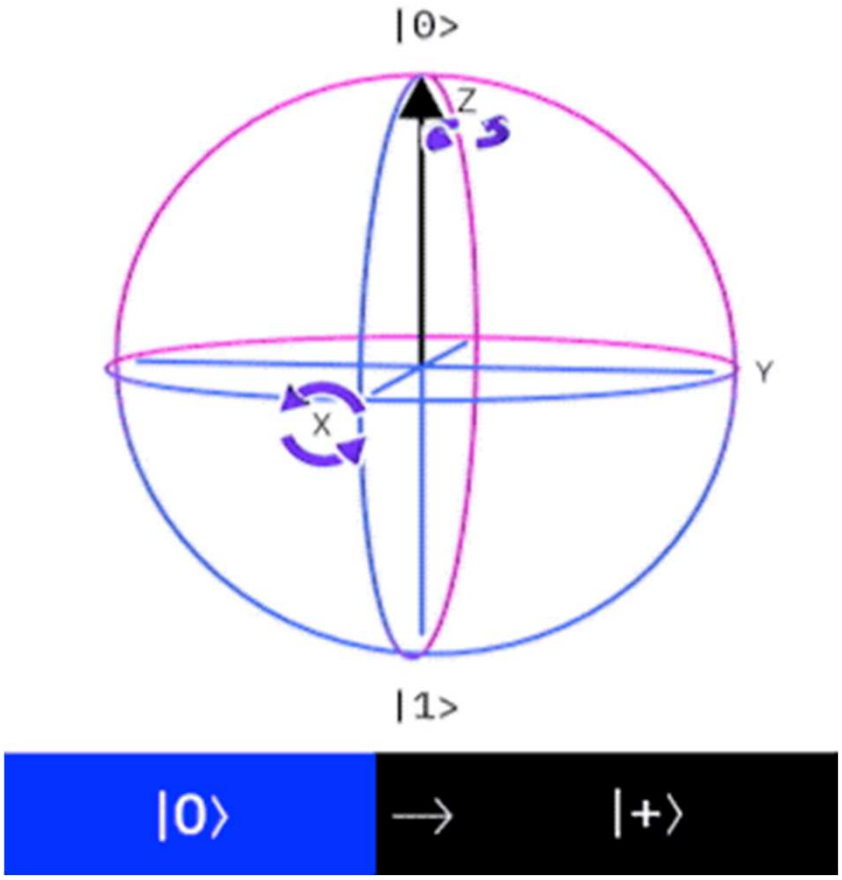


Pauli X gate can reverse qubit state, such as from |0> state to |+1> state.

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$X|0\rangle = |1\rangle,$$
$$X|1\rangle = ?$$

Hadamard logic gate



Pauli X gate can make qubit state to a superposition state, such as from |0> state |+> ($\frac{|0\rangle + |1\rangle}{\sqrt{2}}$)

$$\boldsymbol{H} = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{pmatrix}$$

$$H|0\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$$

$$H|1\rangle = ?$$

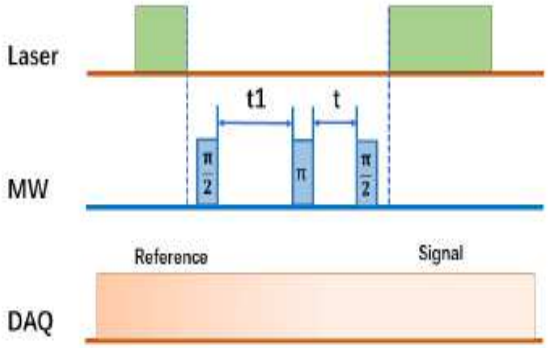
Spin echo experiment

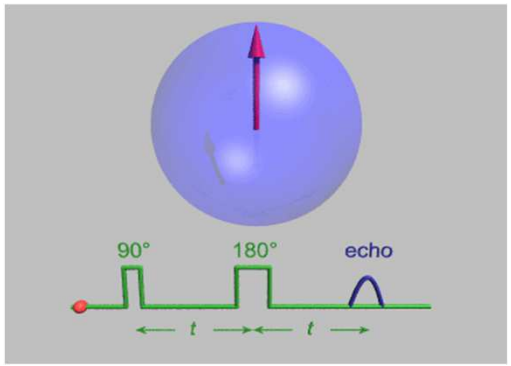
Experimental purpose

① Understanding spin echo experiments, in magnetic resonance experiments, spin relaxation and environmental differences cause different spins to precess at different rates. The echo experiment refers to the process of reuniting spin coherent signals by applying reverse decoupling pulses

② Learn how to measure echoes

Experimental principle





Spin echo animation showing the response of spins (red arrows) in the blue Bloch sphere to the green pulse train

Spin echo experiment

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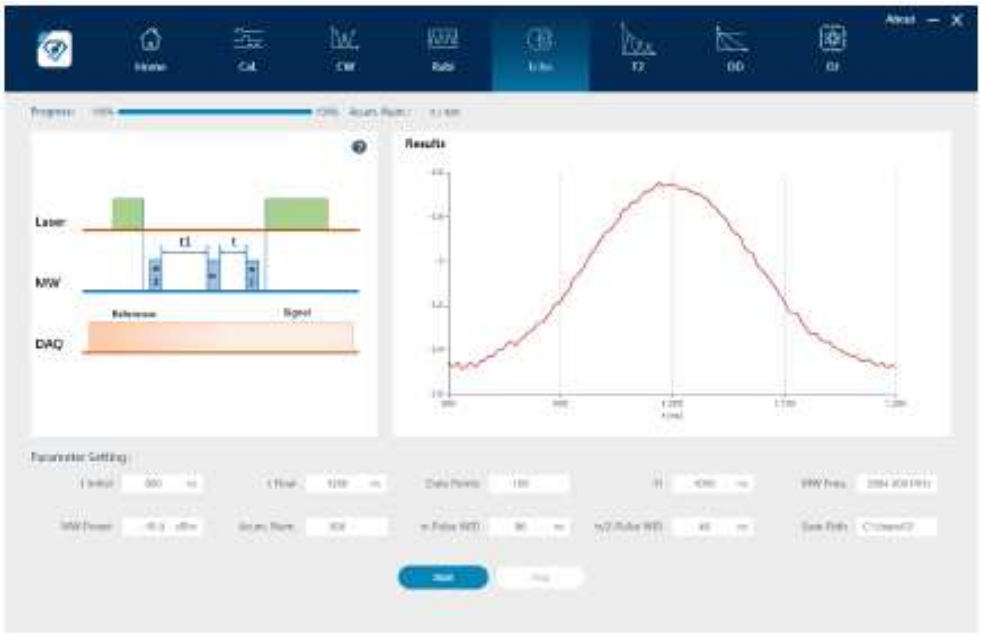
Experimental results



Experimental summary

① The echo experiment measures the echo signal and is used to determine the time of echo detection

② We use the laser to initialize the spin state of the NV color center to the |0> state, then give the spin a free evolution time t1, and apply a reverse decoupling pulse to make the spin converge in the opposite direction. The time t of the reconvergence is different, and the detection signal is also different. When t=t1, the detection signal is the strongest, and the spins are fully converged

T_2 experiment

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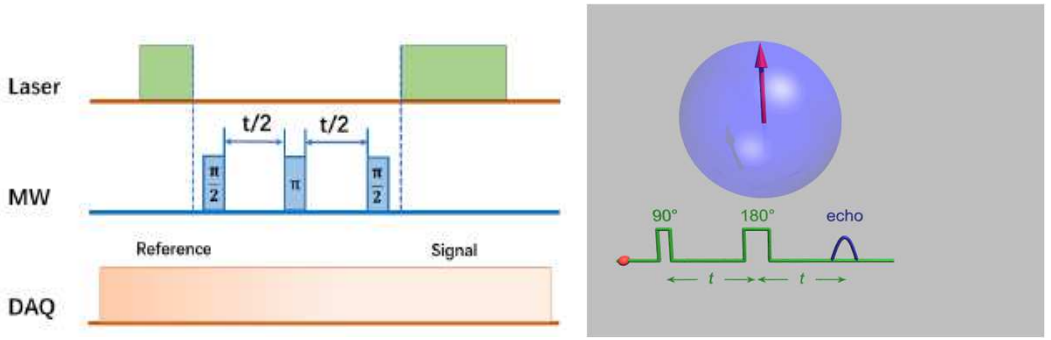
Experimental purpose

① Understanding the T2 experiment: The purpose of the T2 experiment is to measure the decoherence time of NV color center spins. Because a quantum system is not an isolated system, its interaction with the environment will cause decoherence effects

② Understand the cause of decoherence and T_2 time

③ Understand the impact of decoherence, i.e. the time to complete the quantum gate operation before the quantum decoherence

Experimental principle



The spin echo decay animation shows the continuously extending free evolution time, decoherence in which π pulses also fail to refocus spins

T_2 experiment

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Experimental results

Experimental summary

① Quantum systems interact with their environment, causing decoherence effects

② The spin relaxation time can be measured by echo detection, and the T2 time can be obtained by fitting the data.

Fit function is $f = A \cdot \exp(-(t/T2)a) + B$

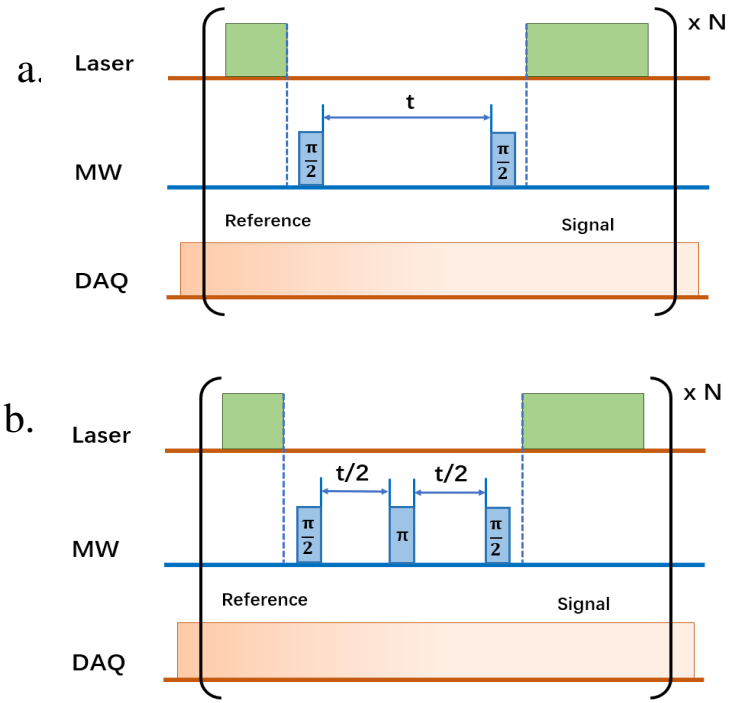
Dynamic Decoupling Experiment

Experimental purpose

① Dynamic decoupling is one of the most intuitive methods to weaken or completely remove this coupling to suppress decoherence

② Dynamic decoupling is a generalization of the average Hamiltonian method in magnetic resonance spectroscopy, that is, the coupling of qubits to the environment is removed out over a specific time period by means of carefully designed pulse sequences

Experimental principle



a. Zero-order dynamics decoupling
b. First-order dynamics decoupling

Dynamic Decoupling Experiment

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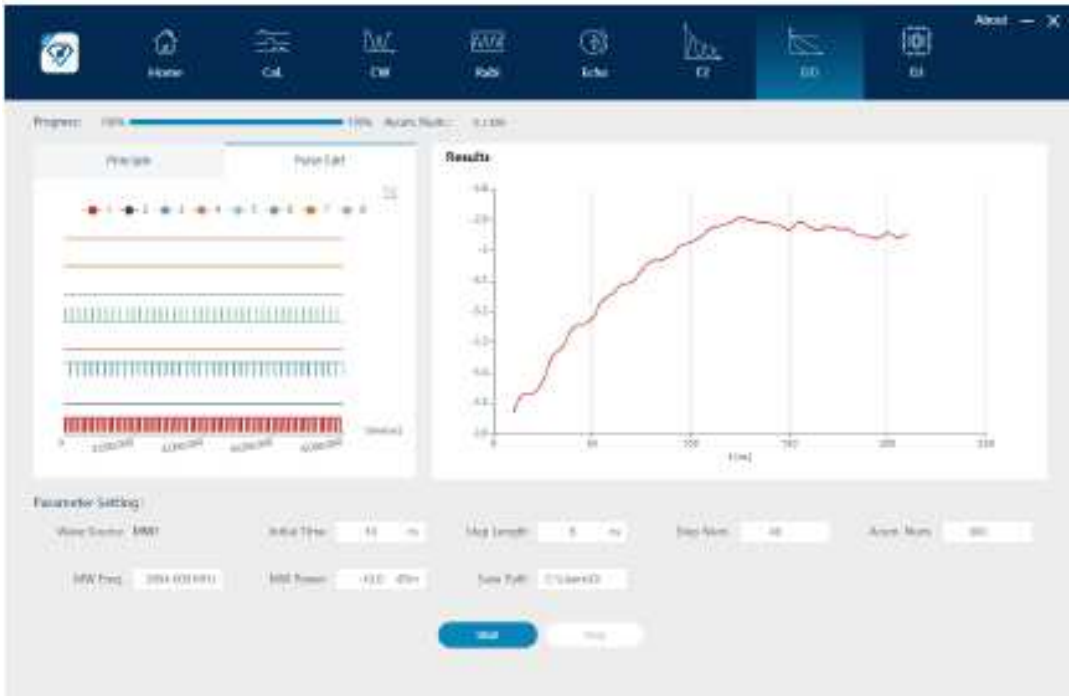
Experimental results



Experimental summary

① Zero-order dynamic decoupling is also a T_2^* experiment or a free induction decay (FID) experiment. The decay time is very fast and the coherence time is short, first-order dynamic decoupling is also equal to T_2 experiment, make the coherence time longer and the decay time is very slower

② Dynamical decoupling can extend coherence time

D.J. algorithm experiment

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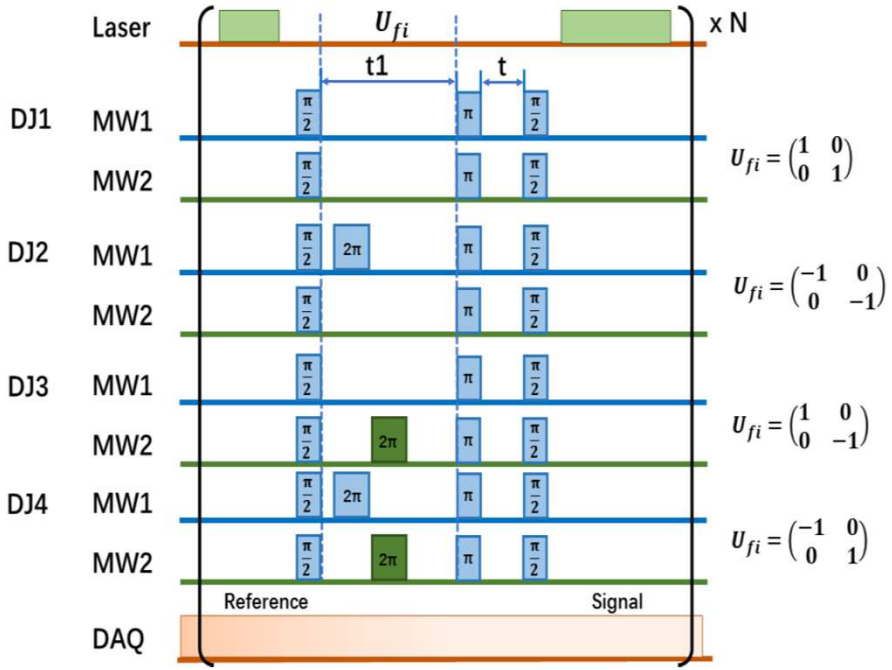
Experimental purpose

① Understand the principle of implementing D.J. algorithm experiments with the NV color center system

② Compare the differences between traditional and quantum algorithms and understand the advantages of quantum algorithms

Experimental principle



D.J. algorithm experiment

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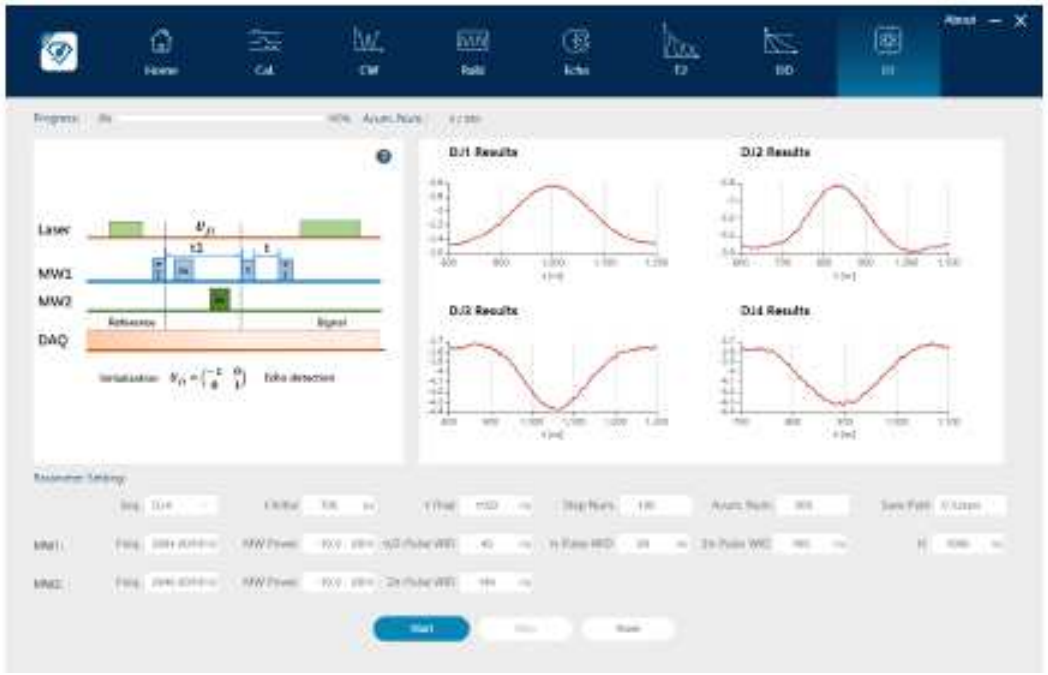
Experimental results



Experimental summary

① Understand the principle of implementing D.J. algorithm experiments with the NV color center system

② Deutsch–Jozsa algorithm is a by-design situation which demonstrates quantum algorithms can be accelerated exponentially relative to classical algorithms. Compare the differences between traditional and quantum algorithms and understand the advantages of quantum algorithms

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Ocean University of China
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天津英华实验学校
South China Normal University affiliated High School
华南师范大学附属中学
Quzhou No.2 High School Zhejiang
浙江省衢州二中
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Customer Referance

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Thank You!