Chapter 12
Electron Spin Qubit in Semicoductor-1-Qubit and 2-Qubit Gates

12.1 Introduction

In Chap.11, we showed how to implement a qubit using electron spin on a silicon substrate. We also demonetrated how to initialize and measure a qubit. In this chapter, we will sudy how to perform a universal 1-qubit gate and a 2-qubit entnaglement gate to fulfill the last two DiVincenzo's criteria (Sect. 1.3). In Chap.10, we showed that by applying a vertical DC magnetic field and a rotating horizontal magnetic field and then *working in the rotating frame*, we would be able to rotate any state on Bloch sphere about any vector. This allows us to build a universal 1-qubit gate (Section 27.4 in [1]) However, in the literature, many silicon qubits are still implemented with the setup in Chap. 9 which means that the qubit is places in a vertical DC magnetic field and a perturbating and linearly oscillating horizontal magnetic field. This is what we will use in this chapter. We will first summarize an experimental paper on how it implements 1-qubit gate. Then we will discuss the implementation of a 2-qubit entnaglement gate with an example.

12.1.1 Learning Outcomes

Be able to describe how a 1-qubit gate can be implemented for silicon spin qubits; understant how a CNOT-gate can be impelmented by using a native entanglement gate of silicon spin qubits and other 1-qubit gates.

12.1.2 Teaching Videos

- Search for Ch12 in this playlist
  - `https//tinyurl.com/3yhze3jn`
- Other Videos
  - `https://youtu.be/0JVw4xICV10`
  - `https//youtu.be/_CpQ-Uy0Kgo`

12.2 1-Qubit Gate Implementation

We will use an example in [2] (with some variation) to demonstrate how to implement electron spin qubit in silicon and the 1-qubit gate. The setup is illustrated in Fig. 12.1.

Firstly, the Hilbert space is created by applying a DC magnetic field pointing to the right. This direction is named the $-\hat{z}$ direction. Therefore, *spin-up means that the spin is pointing to the left, and spin-down means that the spin is pointing to the right*. This is nothing special becuase the name of direction is completely a human definition.

References

1. Hui-Yong, W. *Introduction to Quantum Computing Holes* (Springer, London, 2024).
2. Veldhorst, M. *et al.* An addressable quantum dot qubit with fault-tolerant control-fidelity. *Nature nanotechnology* **9,** 981–985 (2014).