CHAPTER I

INTRODUCTION

1.1 Introduction

Magnetic field measurement plays a crucial role in human activities such as navigation, medical diagnosis, and material characterization (Li et al., 2022). Nowadays, as technology advances and the need for ever-greater precision grows, magnetic field measurement at the nanoscale is increasingly interesting. Therefore, opportunities are opened up for the new innovation such as quantum sensing to improve magnetic field sensing efficiency.

Quantum sensing uses the highly environmentally sensitive quantum state. When a small perturbation interacts with the quantum state, we can trace back to the perturbation quantity from the changed quantum state. For this reason, quantum state can be used as a powerful sensor. The nitrogen Vacancy (NV) center in diamond is an example of a promising ambient quantum system for magnetometry applications. The NV center is a defect in diamond that comes from nitrogen replacement and vacancy formation. As a result, this structure has C_{3V} symmetry, with spin triplet ground states where the $m_s = \pm 1$ can respond to the magnetic field. For example, using the spin triplet ground state of the NV center, one can demonstrate field measurements around magnetic structures and determine the vector magnetic field (Maertz et al., 2010). Utilizing NV for characterization with nuclear magnetic resonance (NMR) technique detect fluorinated sample with hydrogen and fluorine compound via the NV NMR spectra measurement (DeVience et al., 2015). Using NV center increases accurate detection of lower critical magnetic field in superconductors (Joshi et al., 2019).

Conventional NV center studies typically utilize confocal microscopes for high resolution (Acosta et al., 2009), (Gaebel et al., 2006), (Maertz et al., 2010), (Mamin et al., 2013), but it is time-consuming and unsuitable for applications reliant on speed or those were magnetic field changes rapidly. In contrast, Quantum Diamond Spectrometers (QDS) (Bucher et al., 2019) present a promising solution by offering rapid measurement capabilities, particularly suited for applications that prioritize speed over spatial resolution, such as large-scale biosensing and magnetometry.

Real-time magnetic field monitoring remains challenging despite significant scientific advancements in recent years. For instance, the frequency-locking method, which uses a lock-in amplifier to track the optically detected magnetic resonance (ODMR) signal from NV centers, has improved sensitivity to 4.1 μT/Hz with a sweeping ratio of up to 50 μT/s (Ambal and McMichael, 2018). Another noteworthy development involves coherent population trapping, which estimates magnetic field variations from the time series of observed photons (Turner et al., 2022). Recently, the microwave frequency-hopping method has been introduced, enhancing ODMR measurement speed compared to traditional sweeping methods (Liu et al., 2024). These techniques demonstrate in the scanning narrow frequency around 0.1 – 0.2 GHz and low magnetic field.

In this work, we demonstrate the vector magnetometry and mapping unknown magnetic field through optically detected magnetic resonance (ODMR) sequence. The experiments use an ensemble NV center because of the large number of NV center as sensors. In addition, experiments work with rapid magnetic field detection, which uses sweeping mode in a microwave source.

1.2 Research objectives

1.2.1 To demonstrate real-time vector magnetometry using the QDS setup.

1.2.2 To determine the direction and magnitude of the magnetic field using NV center.

1.3 Scope of thesis

1.3.1 We use a type DNV B14 being an ensemble NV center containing NV 4.5 ppm and is grown by chemical vapor deposition (CVD) process.

1.3.2 We perform all experiments in ambient condition.

1.3.3 We use sweep mode of microwave.

1.4 Outline of thesis

This thesis is divided into 5 chapters. Chapter I is the INTRODUCTION consisting of introduction, objective, and scope of thesis. In Chapter II, we describe a brief quantum bit through mathematical equations and Bloch sphere representations. Continuously, we present NV center knowledges such as properties, energy level diagram, Hamiltonian of NV center and Application of using NV center as a sensor. Moreover, we describe a method for studying the NV center. In Chapter III, we show our setup “Quantum Diamond spectrometer” or QDS with presenting optical part and electronics part. In addition, we use ensemble NV center to demonstrate vector magnetometry. In Chapter IV, we discuss the results obtained from the experiments. Finally, we summarize our findings and comments on this work.