Design and Analysis of SiN Optical Waveguide for 2D Beam Steering of small angle

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***Abstract*— The purpose of this research is to address the issue of optical deflection angle in small magnetic devices, which can limit their effectiveness in various applications. To overcome this challenge, we propose using grating couplers to control the direction of light propagation. Specifically, we have developed a system that consists of 16 phase array grating couplers and 8 multimode interferometers (MMIs) that work together to achieve 2D beam steering. The researchers found that changing the wavelength by 50nm was enough to achieve 6.06∘ of 1D beam steering. By carefully manipulating the phase of the grating couplers, we were able to deflect the light from 0∘ to 1.75∘ of 2D beam steering, which could greatly enhance the performance of small magnetic devices.**

Keywords—grating coupler, silicon nitride, phased array, beam steering, FDTD.

I. Introduction

Magnetic sensors with room-temperature operation, high sensitivity, and high resolution are expected to be realized. The superconducting quantum interference device (SQUID) is a highly sensitive magnetometer used in medical instruments to measure human brain's magnetic fields. However, to use a SQUID sensor, precise temperature control at around 4 K is required to ensure quantum-limited operation. The device has demonstrated field resolution at the 10^{-14} T order [1]. In comparison, micro-Hall sensor can operate at room temperature but have the magnetic field resolution around 10^{-6} T [2-3].

The charged nitrogen vacancy (NV) center in diamond is an ideal system for measuring magnetic fields due to its room temperature compatibility and high sensitivity. It is capable of measuring magnetic field around 6 nT. The NV center can be excited by green light at $\lambda = 532\,nm$, and emits a red fluorescence signal at $\lambda = 637\,nm$, making it a miniature magnet detector [4-6]. The incident light needs to change direction to illuminate the NV center to measure the magnetic field.

A typical technique of measuring magnetic fields using NV-centered diamonds is to use a confocal microscope. In addition, two-dimensional mapping of the magnetic field using this technique requires stage movement or beam scanning with mirrors. To make this system compact, the beam scanning must be non-mechanical and integrated with a photodetector[7-10].

We propose the system shown in Figure 1. The red light from the NV center diamond is detected by a Si photodetector without coupling to the diffraction grating. The red light from the NV center diamond is not coupled to the diffraction grating and is detected by a Si photodetector. SiN is used as a suitable optical waveguide for this magnetic sensor. SiN is used for the optical waveguide because of its relatively high refractive index, which is advantageous for miniaturization, and because it is transparent in the green color region.

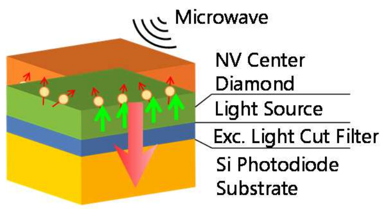

Fig.1 Miniaturization of magnetic measurement system.

In this paper, we present a study of the performance of a SiN grating coupler designed using the finite-difference time-domain (FDTD) technique, with a focus on its ability to achieve 2D beam steering [11]. We analyze the relationship between the coupler's performance and its design parameters, providing a detailed discussion of the findings.

II. Device Structure And Computational Method

Figure 2 shows the total model of the beam steering structure that is based on 16 phased array grating couplers. We used the SiN waveguide to input the green light, and the multimode interferometers (MMI) is used for optical branching. The scanning angles parallel $\theta_{\parallel}$ and perpendicular

$\theta_{\perp}$ to the waveguide can be expressed by the following equation [12].

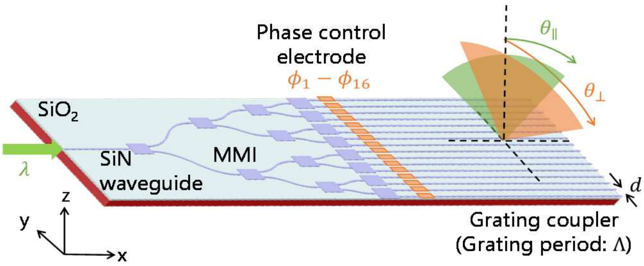

Fig. 2 The total model of phased array grating coupler.

$$\mathrm{Sin}\,\theta \parallel = \frac{n_{eff} - m\frac{\lambda}{\Lambda}}{n_{clad}} \quad (1)$$

$$\sin\theta \perp = \frac{\lambda \Delta\varphi}{2\pi d} \quad (2)$$

Where $n_{eff}, n_{clad}, m, \lambda, \Lambda, \Delta\varphi, and\ d$ are the drop refractive index of the waveguide, refractive index of the cladding layer, mode number, incident light wavelength, grating period, phase difference between waveguides, and waveguide spacing, respectively.

III. Simulation Results

The grating period is set at 340 nm. This is for vertical emission at 532 nm light from grating coupler. The beam scanning angle is calculated by simulation by sweeping the wavelength from 500 nm to 550 nm. Figure 3 shows the wavelength dependence of beam steering angle parallel to the waveguide. The inset images are simulation result of FDTD calculation. The reflected angle is observed to change from 3.18° to -2.88°. By sweeping the incident light wavelength by 50 nm, beam scanning is possible over a range of 6.06°.

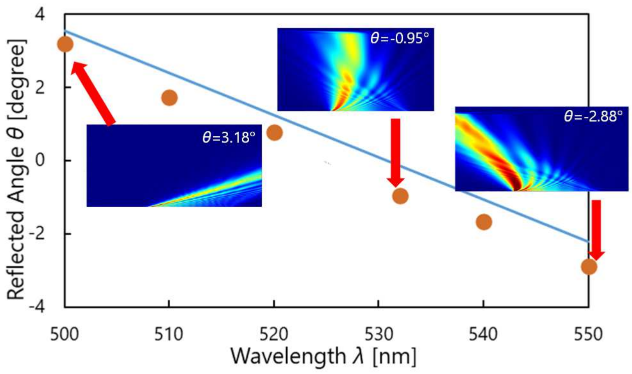

Fig.3 Wavelength dependence of beam steering angle $\theta_{\parallel}$.

Figure 4 shows a 3D FDTD simulation of 2D beam steering, where the $\theta_{\perp}$ can be changed by altering the phase difference from 0° and 22.5°(=π/8 rad). In this case, at a wavelength of 532nm, a change in $\Delta\phi$ of 22.5° can result in achieving $\theta_{\perp} = 1.75°$, allowing for a range of beam steering from 0° to 1.75°

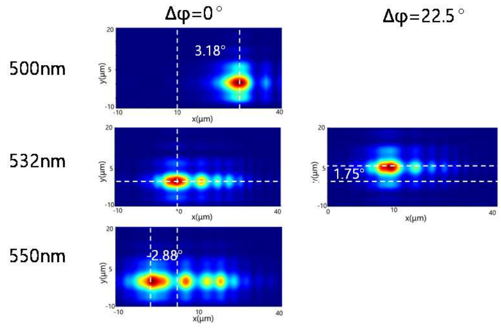

Fig.4 3D FDTD simulation of 2D beam steering.

IV. Conclusion

This paper introduces a novel approach for achieving 2D beam steering using 16 phased array grating couplers. The method involves first designing a single grating coupler that can achieve 1D beam steering of around 6° by changing the wavelength and temperature. Next, a series of 16 phased arrays are established, and a multimode interferometer (MMI) is used to separate the input beam into 16 grating couplers. By carefully changing the phase from 0 to π/8, we were able to achieve 2D steering angles that could be changed by 1.75°. This approach offers several advantages over existing methods, including improved accuracy and flexibility in controlling the direction of light propagation. Furthermore, our results demonstrate the feasibility of using phased array grating couplers for a wide range of applications in which precise beam steering is essential.

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References

[1] R. L. Fagaly, Rev. Sci. Instrum. 77, 101101(2006).
[2] G. shaw et al., Rev. Sci. Instrum. 87, 113702(2016).
[3] G. Boero et al., Sens. Actuator A Phys. 106, 314(2003).
[4] G.Q.Liu et al., Nat. Commun. 10, 1344(2019).
[5] E. D. Herbschleb et al., Nat. Commun. 10, 3766(2019).
[6] Vikas K. Sewani, Am. J. Phys., Vol. 88, (2020)
[7] T. Babaya et al., Dev. C Vol. J103–C, pp. 434–452(2020)
[8] D.N. Hutchison et al., Opt, vol. 3, pp. 887–890, Aug. (2016)
[9] T. Kim, P et al., IEEE, vol. 54, pp. 3061–3074, Sep. (2019).
[10] H. Chen, Appl. Opt., 49, 6455(2010).
[11] X. Yan, IEEE Photon. J., 13, 6600506(2021).
[12] J. Litvik, Proc. of SPIE, 131, 10142(2016).