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An Implantable Wireless Medical System with a High-Gain On-chip Antenna Using Sapphire Substrate

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Abstract

This paper presents a low-radiation loss on-chip antenna using sapphire substrate for wireless medical systems, providing an implantable device with low-power consumption. A low frequency radio wave around 300 MHz is suitable for such a system as avoiding absorption by body, which is a trade-off to the required antenna size. To overcome the trade-off, a high resistive material, sapphire, is utilized for the substrate. The fabricated on-chip antenna using a sapphire substrate can reduce a power consumption of transmitter chip by 95 % compared with that on a silicon substrate. The implemented on-chip antenna was packaged with a CMOS transmitter chip. The emitted radio wave from this transmitter was received using a dipole antenna at the distance of 10 cm place.

1. Introduction

Wireless sensor nodes including various sensors are being studied to broaden sensor application. Although a cubic sensor node has been realized [1], the size of 1 cm^3 is too big to implant in a human body. We have proposed a concept of an implantable wireless medical system as shown in Fig.1, which is a chip size sensor node with 300 MHz due to low absorption by body for medical applications [2,3]. In development of such systems, low-power and small size implementation is necessity and thereby a high gain on-chip antenna is a key component [3].

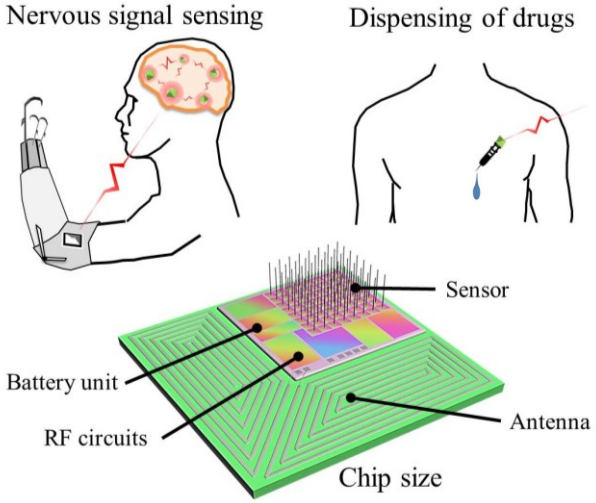

Fig. 1 Concept of implantable wireless medical systems

2. On-chip antenna design

An on-chip antenna using a silicon substrate has a radiation loss [2]. Fig.2 shows an analysis result of the radiation loss mechanism with high frequency structure simulator (HFSS). From this analysis, a surface current is observed near antenna elements on silicon surface, which is generated from radio wave absorbed by low-resistivity silicon.

This paper proposes a low-radiation loss on-chip antenna using sapphire substrate for implantable wireless medical systems. The antenna model is based on a dipole one and the antenna elements are rolled for impedance matching. The reactance part of input impedance is 0 Ω at 300 MHz, when the number of turns is 7 with HFSS. Fig.3 shows the fabricated antenna using aluminum 7 turns patterns of 20 μm width and 1 μm thick. The on-chip antenna has size of 4 mm × 5 mm.

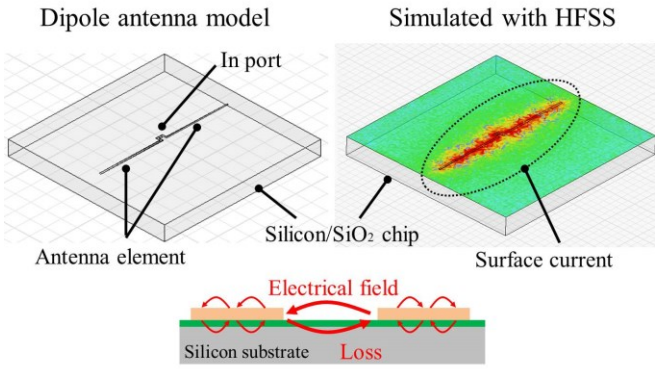

Fig. 2 Radiation loss of antenna on a silicon chip

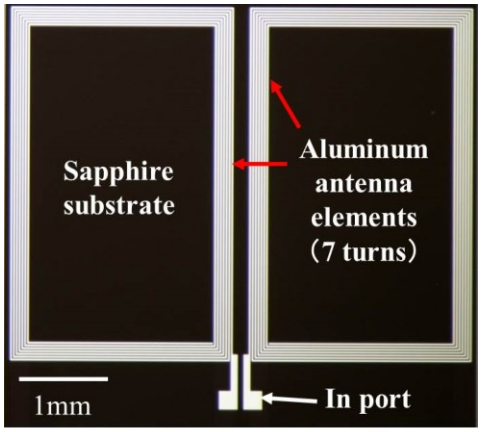

Fig. 3 On-chip antenna fabricated on sapphire substrate

3. Experimental results

Fig.4 shows the simulated and measured return loss (S_{11}) of the fabricated antennas. The center frequency of the on-chip antenna was 360 MHz. The measured return loss was approximately -3.58 dB and the input impedance was 190.5 – j74.7 Ω at 360 MHz.

The radiation characteristic was measured using a dipole antenna which was used for the receiver. Fig.5 shows the antenna gain and directional characteristic of the fabricated on-chip antenna. The maximum antenna gain of the fabricated on-chip antenna using sapphire and silicon substrate were -29.2 dBi and -42.1 dBi at 360 MHz, respectively. According to this result, it is confirmed that the on-chip antenna using a sapphire substrate achieves 12.9-dB higher gain compared with that using a silicon substrate. This improvement means that the fabricated on-chip antenna can reduce a power consumption of transmitter chip by 95 % compared with that on a silicon substrate..

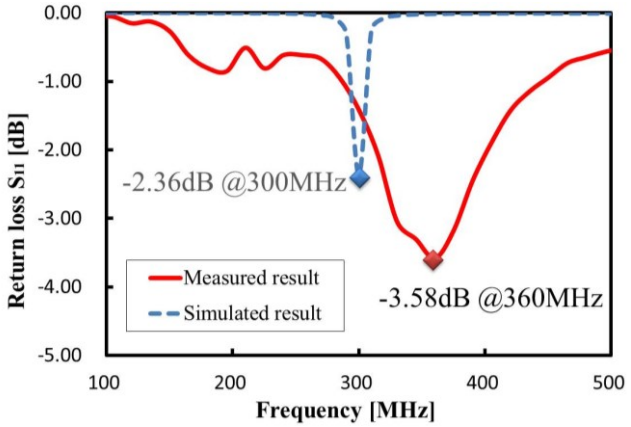

Fig. 4 Simulated and Measured return loss characteristics (S_{11})

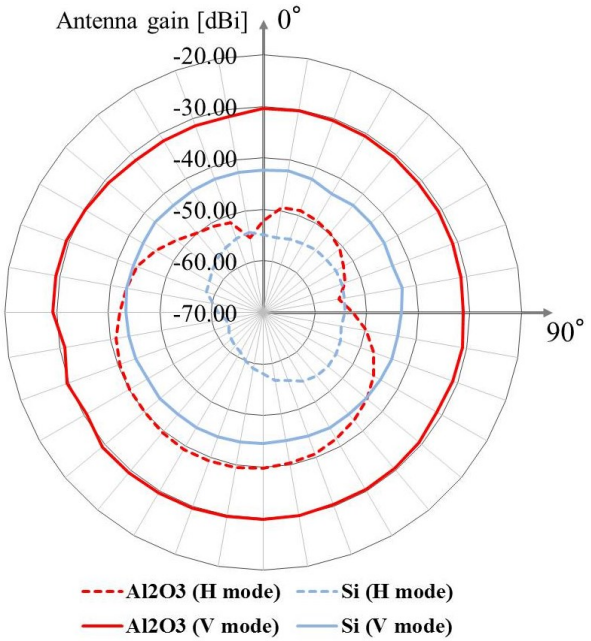

Fig. 5 Gain characteristics of fabricated antenna on a silicon and sapphire substrate (unit [dBi])

4. Demonstration

We demonstrate signal transmission using the proposed on-chip antenna and a CMOS transmitter chip as shown in Fig.6. The CMOS transmitter chip includes modulation circuit, a power amplifier and a power supply circuit. The data signal (1 Mbps) and carrier wave (360 MHz) are input into the transmitter chip. The output signal of the transmitter chip is applied to the fabricated mm-sized antenna. The emitted radio wave is received using a dipole antenna at the distance of 10 cm place. Fig.7 shows the received signal wave. The total power consumption of transmitter chip with on-chip antenna was 6.66 mW and the received power was 0.88 μW. The ratio of received power versus consumed power was -38.8 dB.

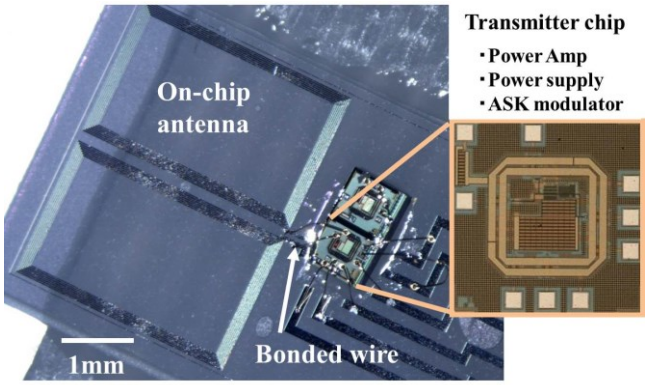

Fig. 6 On-chip antenna with transmitter chip

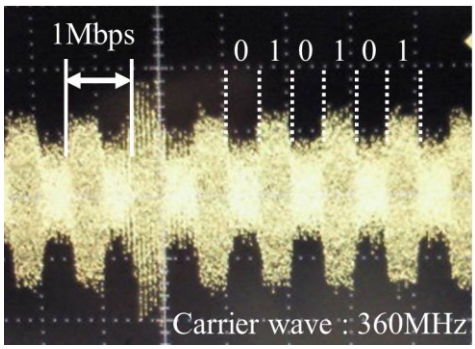

Fig. 7 Measured received signal of on-chip antenna with transmitter chip

5. Conclusion

The on-chip antenna using a sapphire substrate accomplishes 12.9-dB higher gain and can drastically reduce power consumption of transmitter by 95 %. Furthermore, the effectiveness of the fabricated antenna is also confirmed by a demonstration using a chip-size packaged transmitter system.

References

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