Magnetic energy coupling system based on micro-electro-mechanical system coils

Xiuhan Li, Quan Yuan, Tianyang Yang, Jian Liu, and Haixia Zhang

Citation: J. Appl. Phys. 111, 07E734 (2012); doi: 10.1063/1.3680528
View online: http://dx.doi.org/10.1063/1.3680528
View Table of Contents: http://jap.aip.org/resource/1/JAPIAU/v111/i7
Published by the American Institute of Physics.

Related Articles
Optical actuation of microelectromechanical systems using photoelectrowetting
Magnetostatic detection using magnetoresistive sensors with vertical motion flux modulation
Mode characterization of sub-micron equilateral triangular microcavity including material's dispersion effects
Comparison of two experimental methods for the mechanical characterization of thin or thick films from the study of micromachined circular diaphragms
Phase transition behavior in microcantilevers coated with M1-phase VO2 and M2-phase VO2:Cr thin films

Additional information on J. Appl. Phys.
Journal Homepage: http://jap.aip.org/
Journal Information: http://jap.aip.org/about/about_the_journal
Top downloads: http://jap.aip.org/features/most_downloaded
Information for Authors: http://jap.aip.org/authors

ADVERTISEMENT
Magnetic energy coupling system based on micro-electro-mechanical system coils

Xiuhan Li,1,a) Quan Yuan,2 Tianyang Yang,1 Jian Liu,2 and Haixia Zhang2,a)
1School of Electronics and Information Engineering, Beijing Jiaotong University, Beijing 100044, China
2National Key Laboratory of Nano/Micro Fabrication Technology, Institute of Microelectronics, Peking University, Beijing 100871, China

(Presented 3 November 2011; received 2 October 2011; accepted 1 January 2012; published online 14 March 2012)

In this paper, a high efficiency wireless energy transfer system based on MEMS coils is first developed. The permanent magnetic core used in the transmitting coil can not only enhance the magnetic flux but also applies a strong and uniform magnetic field distribution around the core. ANSOFT HFSS is then used to analyze the performance of two coupling coils designed to be resonated at the same frequency. The distribution of magnetic field strength and coupling efficiency is modeled and characterized. High-performance bio-compatible MEMS coils were fabricated on a glass wafer by thick glue photolithography and electroplating technique. We measured a peak value of energy transfer at the resonant frequency of 23 MHz, and the coupling efficiency is higher than 10% within the distance of 10–20 cm by sweeping frequencies from 1 MHz to 200 MHz. Experiments also show that the resonant coupling efficiency is not much affected by the relative position of the two coils in a large range. © 2012 American Institute of Physics. [doi:10.1063/1.3680528]

I. INTRODUCTION

Implanted active medical devices based on micro-electro-mechanical systems (MEMS) technology have been used for a variety of therapeutic, prosthetic, and diagnostic functions.1 Batteries are not suitable for power supply due to their limited lifespan, power density, and low integration level and the biocompatibility constraints of the whole system. Wireless power transfer schemes are often used to avoid both transcutaneous wiring and replacement of the device battery by surgeries.

Magnetic coupling is the primary choice of wireless power transfer due to its non-radiativity for medical application. However, commonly used assembly coils with big volume are difficult to integrated with integrated circuit (IC).2 Moreover, they exhibit drawbacks such as short coupling range (lower than 5 cm), bad directionality, and low coupling efficiency, which decreased sharply while changing the relative position between the two coils.3 Kurs et al. reported that magnetic resonant coupling with four coils can be used for wireless power transfer.4 This scheme has been tested and found feasible and efficient in nonmedical cases because of its large size and inflexibility. The expected diameter for most medical implanted coil was no more than 8 mm.5 MEMS technology offers suitable solutions to design and fabricate high density and performance receiver coil (R coil) with good bio-compatibility and an easy integration with IC.5

Coupled-mode theory6 can be used to calculate magnetic resonant coupling between two ideal models with identical and big size; it is not suitable for coupling coils with great size disparity. We used the numerical simulation tool ANSOFT HFSS to calculate the three-dimensional (3D) model of the coupling coils to get the best performance for the same resonant frequency. An experimental model for bio-energy coupling system is developed. The relationship between the position and the coupling efficiency is characterized and analyzed. Our experimental results show that the coupling between the two self-resonant coils has many priorities compared to the conventional magnetic coupling system: First, the transmitting coil (T coil) with a permanent magnetic core helps to improve the coupling range (15–20 cm) and the efficiency (higher than 10%). Second, it shows good directionality based on magnetic resonant coupling.7 Then our MEMS coil shows better integratability, smaller volume, and better biological compatibility. Finally, the specific aspect ratio (SAR) distribution character for this system was calculated and ensures safety for implanted medical system application.

II. METHOD

The experimental model for biowireless energy coupling system was shown in Fig. 1. The internal part was placed in a cylinder-shaped Plexiglas container filled with simulated body fluid (SBF) solution with a diameter of 25 cm and height of 25 cm; this corresponds to the dimensions of a human chest. SBF is a liquid with similar composition as human body fluid. Hence it was used to simulate the human body environment. The T coil was placed outside of the container. The MEMS R coil was packaged and fixed on a holder to change the positional parameters (such as vertical distance D, angle θ, and lateral distance L) between the two coils. The coupling efficiency was measured by Network analyzer (hp 8714 C). The attenuation factor could be derived through S parameters:

---

*a)Authors to whom correspondence should be addressed. Electronic mail: lixihuans@bjtu.edu.cn and zhang-alice@pku.edu.cn.
Based on the experimental model, a 3D model for T coil and container was built in HFSS. Driven modal solution type and lump port excitation were chosen for numerical simulation. The T coil was built by copper line (the diameter was 2 mm) winding around a magnetic core. The number of turns was 13. The magnetic core was a cube of permanent magnetic material (NdFeB) with dimensions of 89.5 mm (x axis) × 89.5 mm (z axis) × 56 mm (y axis). For the magnetic core, the coercive force was 12.8 KOe, the maximum magnetic energy density was 37.2 MOe, and the remanence was 12.7 KGs. The measured surface magnetic field’s intensity for this magnetic core was 5000 Gs. The permanent magnets could not only enhance the magnetic flux for the T coil but also apply strong and uniform distribution of the magnetic field for long range transmission and good directonality.

The magnetic field distribution around T coil was solved at first. As the induced electromotive force was proportional to the magnetic field intensity (H), the coupling efficiency can be characterized by H. Figure 2(a) showed the magnetic field intensity on the core axial surface inside the container solved in frequency of 28 MHz. It proved that the magnetic field generated by the T coil was strong and uniform in a larger range. Local and average SAR distribution curves under the frequency of 28 MHz was shown in Fig. 2(b). The maximum SAR was lower than the 0.4 W/kg value of the C95.1-2005 standard set by the Institute of Electrical and Electronics Engineers (IEEE). Therefore this wireless energy transfer system is safe for medical implant application.

Power transfer efficiency had a strong dependency on the quality factor (Q). The relationship between Q and frequency for T coil was simulated by HFSS as shown in Fig. 2(c). The peak value of Q = 15 was obtained at the frequency of 28 MHz. The performance of MEMS R coils was also calculated and optimized by HFSS. Figure 2(d) shows the simulation results for coils with different line width and spacing in the frequency range of 10–30 MHz. The highest Q was obtained at the width of 200 μm and 100 μm spacing between the wires in the frequency range of 20–25 MHz. The thickness was 15 μm, and the number of turns was 9.

III. FABRICATION OF MEMS COILS

High performance MEMS R coils were fabricated on a glass wafer by thick glue photolithography and electroplating techniques. The process flow was shown in Fig. 3(a). A 0.5 μm thick SiC film was first deposited and patterned. This film acts as a mask for glass wet etching. After etching of the glass wafer, a 1 μm thick copper layer was sputtered and stripped to form the underpass. Then 1 μm thick SiO₂ film was deposited by plasma enhanced chemical vapor deposition (PECVD) as the dielectric layer. After the link hole etching, a seed layer was sputtered on the wafer. Next, the coils were patterned with thick photoresist and formed by copper electroplating. Finally, the MEMS coils were released by removing photoresist and seed layers. Figure 3(b) shows a scanning electron microscope (SEM) image of MEMS coil.

IV. RESULTS AND DISCUSSION

Figure 4 shows the measurement results for T coil and packaged MEMS R coils. Both of the coils could acquire...
their highest Q in the frequency range of 21–23 MHz. It can be derived that two coils resonate at the same frequency range. Only few deviations between the experimental and simulation models were measured. It might be caused by the simplification of the coil model and the fabrication process.

The RF attenuation factor (Eq. (1)) between two coils was measured with the experiment setup shown in Fig. 1. The measurement results for RF attenuation versus positional parameters such as vertical distance (a), angle (b), and lateral distance (c) is shown in Fig. 5. The minimum power attenuation was gained as $-9.3$ dB at frequencies around 23 MHz, which was close to the measured resonant frequency. The RF attenuation factor was not affected by the positional parameters. Figure 5(d) was the measured relationship between transmitted power (TP) and received power (RP). When the TP was lower than 55 mW, the RP increased linearly with the TP and the highest efficiency was more than 10%. However, the RP was not increased with the TP after the saturation point. For the T coil, the electric current and intensity of magnetization increased with TP. When the transmitting magnetic core saturated, the intensity of magnetization was not increased with the TP due to the inflection point in magnetic hysteresis loop. Hence there existed a saturation point for RP.

V. CONCLUSIONS

In summary, we present a wireless energy transfer scheme using winded T coil and MEMS R coil. A hard magnetic material core was used in T coil to produce stronger and better directional coupling. Numerical simulation methods were used to model and calculate Q for T and R coils. The MEMS R coil was successfully designed and fabricated with small size and higher performance. Because the two coils are coupled in magnetic resonance status, the coupling efficiency of this system shows good directionality and higher coupling efficiency. This system can successfully deliver the energy of 5 mW in a large range (10–20 cm).

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (60706031 and 61176103), the Fundamental Research Funds for the Central Universities (2011JBM202 and 2011JBZ002), and the “Talents Project” of Beijing Jiaotong University.