Micromachined Silicon Generator for Harvesting Power from Vibrations

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Introduction

The rapid growth in the field of wireless sensor networks has highlighted the issue of powering remote sensor nodes. The requirement to change batteries, or refuel other power sources, places an unwanted additional maintenance and cost burden on such wireless networks. In certain applications where environmental vibrations are present, there is the opportunity to harvest the kinetic energy of these vibrations and use this to power the remote sensor node

This poster introduces the design of an electromagnetic micromachined silicon generator. The paper presents a comprehensive simulation of both the mechanical and magnetic characteristics of the device and the optimum design. Finally, the silicon micromachining approach currently being employed to fabricate the devices is discussed.

Electromagnetic Micromachined Silicon Generator Design

The micromachined generator is based upon a larger design developed at the University of Southampton. This arrangement uses a four magnet configuration, with the magnets located on a stainless steel beam designed to vibrate at resonance.

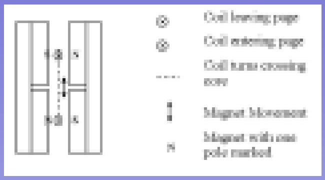


Figure 1 - Original generator configuration.

A coil is located between the 4 magnets such that the flux lines and the direction of motion are perpendicular to the coil windings. The configuration is shown in figure 1. The micro generator, shown in figure 2, is therefore based upon this configuration and is designed to be realisable using standard silicon micromachining techniques

The coil is located in a silicon paddle which is supported by a beam 1mm long, 525µm thick and 500µm/400µm/300µm wide for models A, B and C respectively. Two magnets are located within etched recesses in each Pyrex wafer and a Pyrex wafer is anodically bonded to each face of the silicon wafer. The bonding process is aligned to ensure correct placement of the coil relative to the magnets and the paddle is deep reactive ion etched (DRIE) through the thickness of the wafer. Electrical connection is provided by bond pads located at the die perimeter.

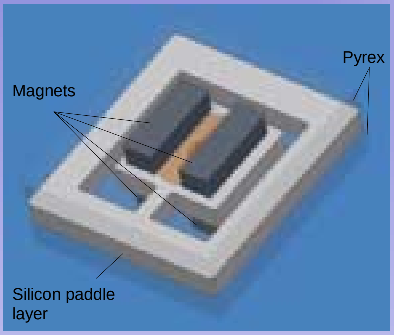


Figure 2 - Micromachined silicon generator

Finite Element Modelling

The generator is designed to operate at resonance, its first mode being a lateral vibration in the plane of the wafer as shown in figure 3. A second configuration with a double beam support is also shown in figure 3.

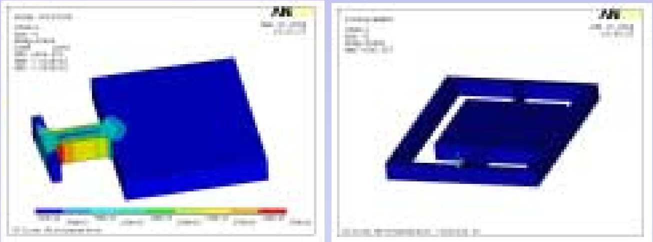


Figure 3 – FE plots of operational mode of single and double beam generator designs

Model	Mode 1 (kHz)	Mode 2 (kHz)	Mode 3 (kHz)	Max stress
A	12.6	13.45	29.5	4.5
B	9.5	12.4	25.9	3.5
C	6.4	11	20	2.6

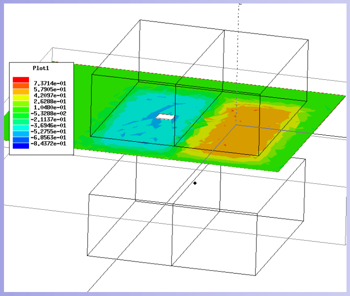
Table 1 – FE results for the single beam generator

The double beam configuration has a resonant frequency of 39.5 kHz. The resonant frequencies of the first 3 modes of the single beam generator (Models A, B and C) are given in table 1. This table also includes the maximum stress experienced by the silicon at the maximum displacement of 140µm. These stresses are well within the fracture strength of silicon.

Magnetic Modelling

Electromagnetic FEA simulations using Ansoft’s Maxwell 2D have also been performed to determine the voltages which can be generated from the single beam generator designs. The modelling considers 2 types of coil:

- An electroplated copper integrated coil consisting of a square spiral of 71 turns with each turn being 10µm wide, 10µm thick with a spacing between the turns of 10µm. Resistance 77 Ohms.
- A wound discrete copper coil with 25mm wire and 390 turns. Resistance 109 Ohms.



The magnets used are 1 mm x 1mm x 0.75 mm thick, sintered, NdFeB magnets. The results from an 3D FEA simulation showing the flux density distribution from the magnets is shown in fig.4. As can be seen from the plot a flux density of approximately 0.5 T exists in the gap between the magnets.

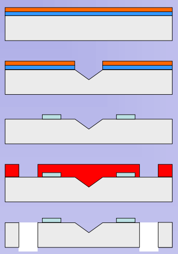
Figure 4 – FEA simulation of flux density

Table 2 gives the predicted results for the voltages and power generated according to the FE simulation for all three beam geometries. For the purposes of the 2D simulation the depth of model is assumed to be the mean diameter of the coil, which is 1.6 mm in this case. The results are given for the devices operating at resonance and at maximum amplitude. Two types of coil have been simulated: an integrated coil and a wound copper coil

Model	Resonant frequency (kHz)	Wire-wound No load Voltage (V)	Power delivered to 100 Ω load (mW)	Micro-fabricated No load Voltage (V)	Power delivered to 100 Ω load (mW)
A	**12.6**	**4.0**	**36.62**	**0.76**	**1.84**
B	**9.5**	**3.0**	**20.60**	**0.57**	**1.03**
C	**6.4**	**2.0**	**9.15**	**0.38**	**0.46**

Table 2 – FEA calculated voltages and power

Fabrication



Grow 1µm SiO_2
Deposit 160nm $Si_3 N_4$

Photolith trench, Dry etch SiO_2 and Si_3N_4 Wet KOH etch Si

Strip SiO_2 and Si_3N_4, evaporate 1µm Al , Photolith and wet etch Al

Photolith Si paddle SPR220 resist, 20µm thick

DRIE Si through wafer
Strip resist

Figure 5 – Fabrication processes

Figure 5 shows the fabrication process and figures 7 and 8 show the finished etched devices for the discrete coil generator. The integrated coil generator and Pyrex wafers are currently being fabricated.

Figure 6 – Photo of single beam device

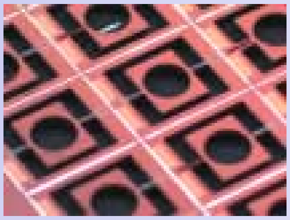


Figure 7 – Photo of double beam device

Conclusions

This poster presents details of a comprehensive design and simulation study of a resonant electromagnetic vibration powered generator. Resonant frequencies vary between 6.4 and 12.6kHz and the stress simulation has identified the maximum safe displacement of the generator coil. The magnetic simulation has predicted maximum power levels generated of 36mW at a resonance of 12.6 kHz for Model A at maximum amplitude. In practice power levels generated will depend upon the vibration spectra of the application and the ability to generate the maximum coil amplitude. In some circumstances the lower frequency devices may provide more power.

Acknowledgements

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