PARYLENE HT FOR ELECTRET GENERATORS

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Abstract: The use of parylene HT as an electret material is presented. As other parylene variants, deposition of parylene HT is a room-temperature chemical vapor process and parylene HT is MEMS/CMOS process compatible. Compared to Teflon AF, PTFE and CYTOP, parylene HT has much superior charge densities. After corona charging, the highest charge density observed is 3.69 mC/m^2, equivalent to a surface potential of 204.58 V/μm. A micro power generator with metal rotors and parylene HT electret is developed. The power output is 5.6μW at 50Hz with an external load of 100MΩ.

Key Words: micro power generation, energy harvesting, polymer electret, parylene HT

1. INTRODUCTION

Energy scavengers that can harvest waste energy from ambient resources such as natural vibrations, human motions, equipment vibrations and so on have received attention of many researchers in the last decade.

Generally, energy scavengers use two methods to harvest energy from linear vibrations. A piezoelectric harvester uses piezoelectric material to convert strain in the spring into energy [1, 2, 3]. An electromagnetic generator harvests energy by a magnet attached to the proof mass inducing voltages in a coil during linear motion [4, 5].

Most published energy scavengers that harvest energy from linear motions have structures of spring and proof mass. These energy harvesters inherently have resonant frequencies and thus certain narrow bandwidth around the mechanical resonant frequency, while natural harvestable vibration power spectrum usually spans from low to ~100 Hz with higher energy in the low frequency end.

To overcome this problem and harvest energy in the low frequency range, new energy harvesters without spring–proof–mass structures has emerged as a solution [6].

2. DESIGN OF ELECTRET GENERATOR

Boland et al developed the first design of micro electret power generators without spring proof mass structures [6, 7]. A capacitor-like structure was employed, as shown in Figure 1. Since then, almost all electret power generators use the same design [8, 9]. Power generators taking such designs inevitably have internal capacitive impedance in addition to external loads.

From Boland et al [7] and Tsutsumino et al [8], the maximum power output can be given as

$$P_{MAX} = \frac{\sigma^2}{4\varepsilon_0\varepsilon_1\left(\dfrac{\varepsilon_1 g}{\varepsilon_2 d}+1\right)} \cdot \frac{dA(t)}{dt} \tag{1}$$

Where $\varepsilon_1, \varepsilon_2$ are dielectric constants of electret and air respectively, ε_0 is vacuum permittivity, g is gap distance between top rotor and electret and d is the thickness of the electret. From this equation, the maximum power decreases as the gap distance increases. That said, careful and precise gap control is required to achieve high power output.

To eliminate hassles and complexity of gap control, we demonstrated a design that puts two output electrodes on the stator, electret material is applied on the stator and the rotor is a piece of metal to couple both electrodes [10]. Both the rotor and stator are pieces of glass with patterned electrodes and the power is generated when there are relative motions between these two plates, as shown in Figure 2.

However, one drawback of that design is the difficulty to control the movement of the top rotor plate and to keep it in contact with the stator plate during motions. To overcome this, we developed a new design that the rotor is a metal block confined within an external acrylic container. Meanwhile, the metal rotor can keep in contact with the stator all the time by the gravity of the metal mass itself and the coulomb attraction force between charges on the rotor and stator. Figure 3 shows the packaging schematic.
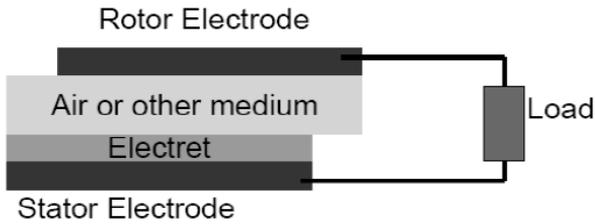
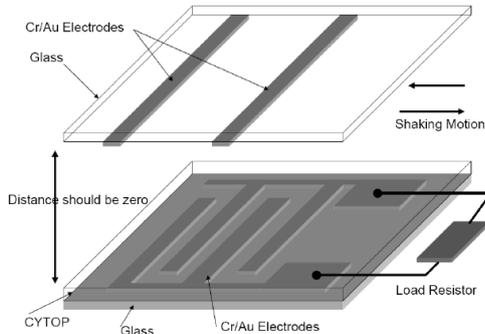Figure 1. Capacitor-like generator design
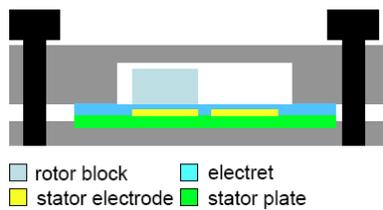

Figure 2. Generators with 2 electrodes on stator

Figure 3. Improved packaging design

3. POLYMER ELECTRETS

Many materials have been explored for the use as electret. Hsieh et al demonstrated MEMS electret microphone using Teflon AF [11]. Later on, Boland et al developed a Teflon AF electret power generator [6]. CYTOP was first introduced to micro power generator by Tsutsumino et al [12]. Sterken et al demonstrated a generator using oxide/nitride as electret [9]. Among these explored materials, CYTOP is reported to have highest surface charge density, $2.8 mC/m^2$ [12].

From Equation 1, the maximum power output of an electret power generator is proportional to the surface charge density squared. Therefore, it is desirable to find an electret material with high surface charge densities. Specialty Coating Systems introduced a new parylene variant, SCS Parylene HT, shown in Figure 4. Like other parylene variants, parylene HT is deposited via a room temperature chemical vapor deposition (CVD) process.

To implant charges onto parylene HT surfaces,

corona charging technique is employed. The optimized corona charging conditions are listed in Table 1. Automatic isoprobe surface potential measurement equipment is used to measure the distribution of the surface potential of parylene HT.

Figure 5 shows the distribution of surface potential per micron of parylene HT. The highest surface potential observed is 204.58 V/μm, equivalent to a surface charge density of 3.69 mC/m^2.
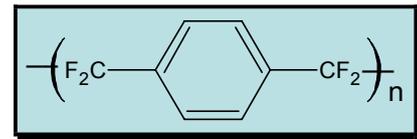

Figure 4. SCS Parylene HT from Specialty Coating Systems.

Base current	0.02 μA
Grid current	0.2 μA
Substrate Temperature	100 ^oC
Charging time	60 minutes

Table 1. Optimized corona charging conditions
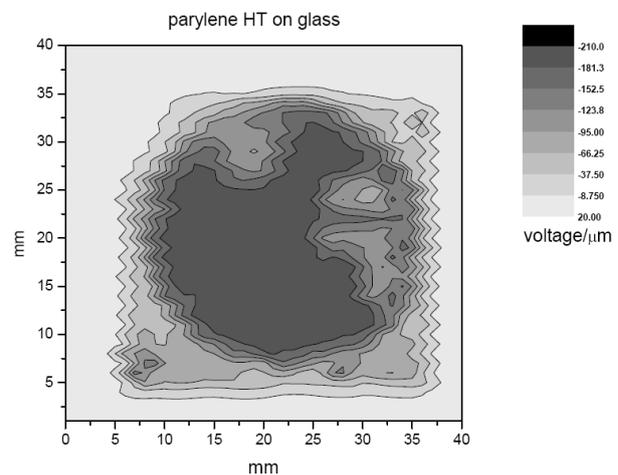

Figure 5. Distribution of surface potential per micron of 7.32-μm parylene HT film after corona charging.

4. DEVICE FABRICATION

The device fabrication starts with soda lime glass wafers. 2000Å Au and 100Å Cr are thermally evaporated and patterned as the power

output electrodes via conventional photolithographic processes. The electrodes are 5mm by 5mm with 2mm spacing for each cell. Next, the glass wafer is diced into 30mm-by-30mm stators. After dicing, 7.32-μm parylene HT is deposited on the stator. Similar to parylene C and other parylene variant, parylene HT is deposited via the room temperature CVD process. After deposition, corona charging is done to implant charges on parylene HT. Optimized conditions are listed in Table 1.

The rotors are CNC-machined to be 4.5mm by 4.5mm by 2mm (L by W by H) brass blocks. The container is also CNC-machined out of acrylic material. The final assembled device is shown in Figure 6.

5. POWER GENERATION

The generator assembly was mounted onto a CNC-machined acrylic stage that is fixed to the electrodynamic shaker. All necessary wires were soldered. Power generation experiments were performed using a Labworks Inc. ET-132-2 electrodynamic shaker, which was driven sinusoidally by a HP33120A function generator through a power amplifier. The acceleration of the power generator was measured using an Endevco256HX-10 accelerometer. The micro electret power generator was connected to a resistive load. In order to measure large output voltages, a simple two-resistor voltage divider was used as the load. The output voltage was measured through a National Semiconductor LF356N op-amp, which is a 10^{12}-ohm input impedance voltage buffer. The shaking amplitude is defined by the external packaging container. For this device, the shaking amplitude is $2mm_{p-p}$. The frequency is varied from 10Hz to 70Hz and the load resistance from 50Mohm to 2000Mohm.

Figure 7 shows power output as a function of load resistance and Figure 8 shows power output as a function of frequency. Due to the capacitive nature of the device, there is an optimal load for the optimal power generation. Experimentally, it is found to be 100-200 MΩ, in good agreement with our theoretical prediction. Using the optimal 100 MΩ load, a maximum power output of 5.6μW at 50Hz with a sinusoidal-like waveform is produced. Time traces of output voltage are shown in Fig 9.
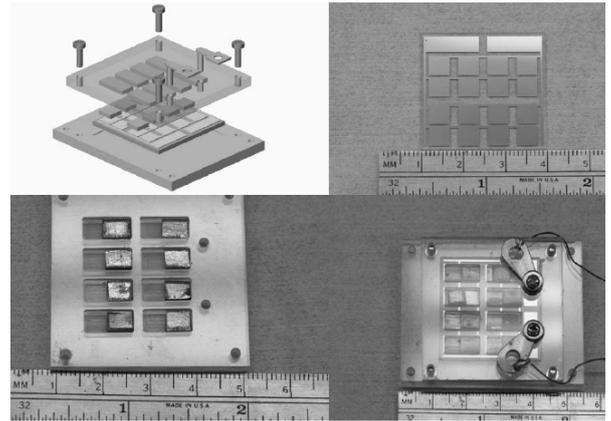

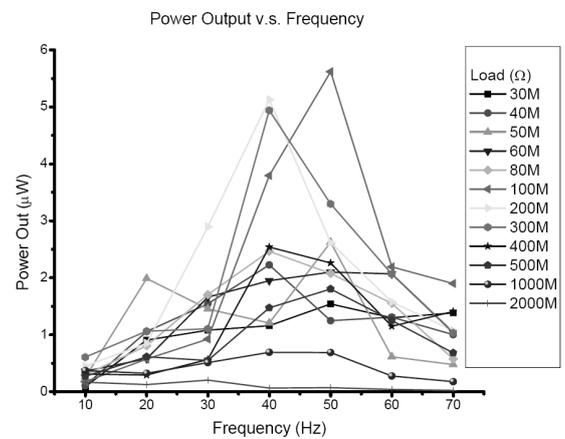*Figure 6. Schematic and photograph of stator, rotor and assembled devices.*

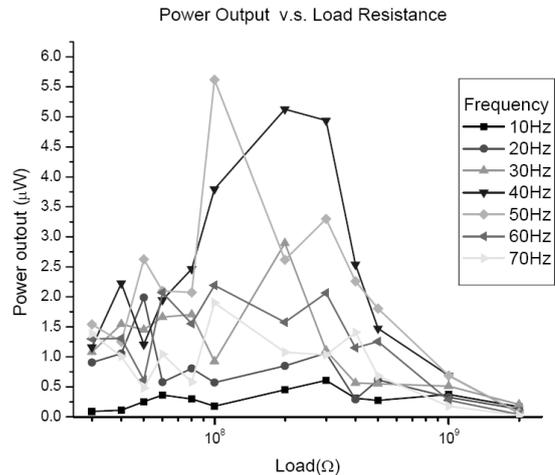*Figure 7. Power output versus frequency*

Figure 8. Power output versus load resistance

One important issue of our generator is tearing and wearing problem. After testing, the surface of parylene HT was scratched by the rough surface of poorly-machined brass rotor blocks. The surface potential decreased, too.
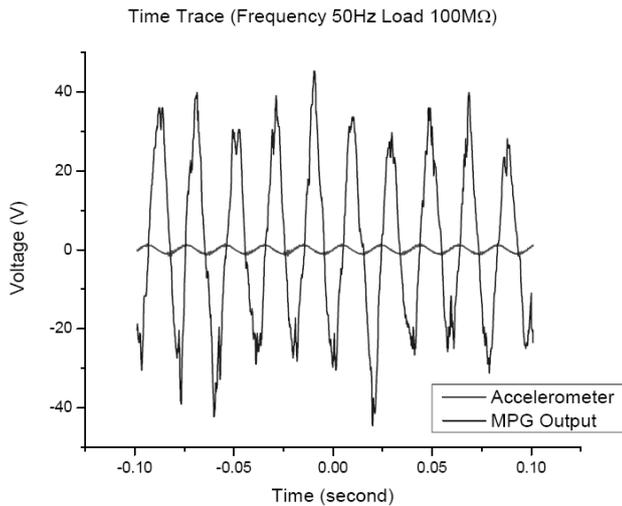
Time Trace (Frequency 50Hz Load 100MΩ)

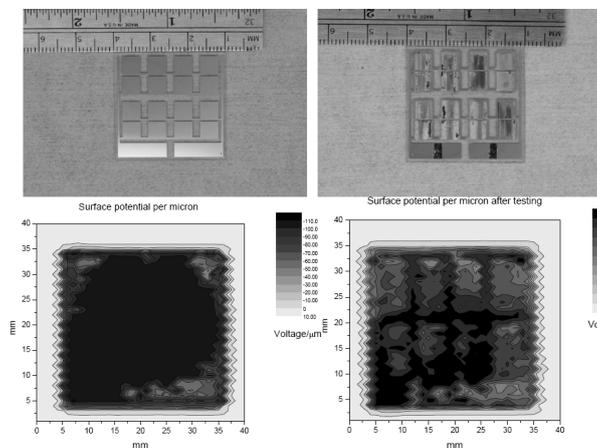Figure 9. Time traces of voltage output

Figure 10. Surface and surface potential of parylene HT before and after testing.

Figure 10 shows the surface of parylene HT and the distribution of surface potential before and after testing. The surface potential dropped from 100V/μm to around 60 V/μm. This problem can be prevented by carefully polishing the surface of rotor blocks after machining processes.

6. CONCLUSION

We demonstrated an improved electret micro power generator. This generator used metal as rotors and both the output electrodes were placed on the stator. With a CNC-machined external packaging container, movement of rotors was confined within fixed ranges.

For the first time, Parylene HT was used as an electret material. Charges were successfully implanted onto parylene HT surfaces via corona charging. The highest surface charge density observed is 3.69 mC/m^2. The maximum power output of this generator is 5.6μW at 50Hz with an external load of 100MΩ.

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