Design of MEMS Piezoelectric Vibrational Energy Harvesters for Industrial and Commercial Applications

Kathleen M. Vaeth, Vice President of Engineering

© 2014 MicroGen Systems Inc.
MicroGen Systems Inc. is developing MEMS piezoelectric vibrational energy harvesters.

- **Technology** developed at University of Vermont and Cornell University
- **First prototypes validated** in 2011
- **Production**: X-FAB Semiconductor Foundries (Germany)

"Ten analog, MEMS and sensor startups to watch in 2014" [EE Times (Jan 7, 2014)]

2013 Winner
MEMS Tech Showcase® MEMS Industry Group
[PRWEB (Nov 19, 2013)]

2012 EE Times’ “Silicon 60” Top 60 Emerging Companies in the World [EE Times (Oct 4, 2012)]

© 2014 MicroGen Systems Inc.
There are predictions of one trillion sensors being produced per year by 2020

The all need power  Energy Harvesting

© 2014 MicroGen Systems Inc.
Solution: Micro-scale power source

MEMS Piezoelectric Vibrational Energy Harvesters and Power Cells

- Superior power generation from small form-factors
- Low cost, long life, high reliability and green energy

Power 50-200 µW DC

© 2014 MicroGen Systems Inc.
Power Cell

Electronics (AC/DC conversion)

harvester

Indicator

LED

© MicroGen Systems Inc.
Harvester Cross-Section: MEMS

piezoelectric stack

cantilever

Frame
Mass

© 2014 MicroGen Systems Inc.

Al
Passivation
AlN
Electrode
Cantilever
Si
Oxide

© 2014 MicroGen Systems Inc.
Resonant Mode Energy Harvesting

Deep cavity (~1-2 mm) packaging required, depending on frequency

Bottom View

Cantilever coated with piezoelectric material
Point of high stress:
*Need to prevent overdeflection*
Harvester Cross-Section: Packaging

- Wafer Level Package Cap
- vacuum
- Frame
- Mass
- Borofloat
- Glass Frit
- Al
- Passivation
- AlN
- Electrode
- Cantilever
- Si
- Oxide

© 2014 MicroGen Systems Inc.
Wafer Level Packaged Devices
Enclosed packaging prevents overextension of the harvester, but control of the movement of the cantilever is still required in order to prevent breakage.

Where should the stopper be placed?

- Desired
- What is happening: High strain causes fracture
- Corrected with “stopper”

© 2014 MicroGen Systems Inc.
Stabilization of cantilever movement achieved by incorporation of a stopper on the top and bottom WLP caps.
“Resonant mode” Operation: MicroGen’s BOLT™ Product Line

Resonant frequency \( f_1 \sim \left( \frac{k}{M} \right)^{\frac{1}{2}} \)

Q factor > 250

© 2014 MicroGen Systems Inc.
Machine to machine (M2M) connectivity
Process automation (e.g. oil & gas industry)
Equipment preventative maintenance

Constant Commissioning (Smart Buildings)

Real-time monitoring for structural integrity

Design Parameters: Low G and Frequency, Specifically Tuned Frequency

© 2014 MicroGen Systems Inc.
Design for Frequency Tuning

Predicted and Experimental Resonant Frequencies

- Cantilever L1, Modeled
- Cantilever L1, Experimental
- Cantilever L2, Modeled
- Cantilever L2, Experimental
- Cantilever L3, Modeled
- Cantilever L3, Experimental

FEM Modeling

cantilever angle

Modeled Frequency is within 5% of experimental observations
Frequencies from 100 – 1500 Hz typical

© 2014 MicroGen Systems Inc.
Demos

Powering off of real devices @ 120 Hz

© 2014 MicroGen Systems Inc.
Examples

Powering off of real devices @ 120 Hz
Powering a LTC DC9003A-B SmartMesh™ IP Mote

Power Cell and Mote Manager

Dust mote powered by MicroGen Power Cell

© 2014 MicroGen Systems Inc.
Powering an Anaren Temperature Sensing Mote and LCD Display

Sharp Memory LCD Display

CC110L AIR Module

© 2014 MicroGen Systems Inc.
Harvesting from Building Air Handling System

- **Mote**
- **Harvester**
- **Energy Storage**

---

Graphs showing:
- **Accel(G) vs Freq**
- **Data_Logging, Temp & Volt vs Date-Time**

- Battery Charging!

© 2014 MicroGen Systems Inc.
A high Q oscillator will “ring” at its resonant frequency when impulsed. Our harvester will ring, generating power/energy each time it is struck.

We call this design:

“VIBE” = Vibration Impulsed Broadband Excitation
IoT Example: Tire Management System (TMS) Sensor mounted in tread of tire

TMS unit in tire tread

Actual TMS unit with power source inside

Continental Develops Tread Depth E-Sensor As reported on May 8th 2014, Tire Review (Online)

Design Parameters: High G, High Frequency, Minimal Tuning
Harvesting from Impulses

video

© 2014 MicroGen Systems Inc.
Powering a TPMS unit from a double impulse

- Harvester
- Double impulse generator
- TPMS

© 2014 MicroGen Systems Inc.
Summary

• MicroGen’s piezoelectric energy harvesting Power Cells have the potential to expand the power available for integrated wireless sensors.
  – Frequencies of 100 – 1500 Hz
  – Powers of 50 – 200 µW

• Multiple recent demonstrations include:
  – Powering of wireless temperature sensor network in a building exhaust fan system
  – Powering off electrical frequencies (multiples of 60 Hz)
  – Powering a TPMS unit under double impulse conditions
Thank You!
Various YouTube video demos

Vibration Powered Motion Sensing Demo using Analog Devices’ ADXL362Z accelerometer
You Tube November 15, 2013
Click here to view demo

BOLT™ energy harvester enables Linear Technology SmartMesh™ IP network
You Tube May 10, 2013
Click here to view demo

UAV 'drone' vibration power!!
You Tube October 28, 2013
Click here to view demo

Distributed power/ vibration transmission and energy harvesting
You Tube April 18, 2013
Click here to view demo

Impulse VIBE™ demo
Operation mode for Smart Tire/TPMS
You Tube October 28, 2013
Click here to view demo

Batteries NOT Included
Industrial and building applications
You Tube – March 29, 2013 (~6,000 views)
Click here to view demo