Nuclear Microbatteries

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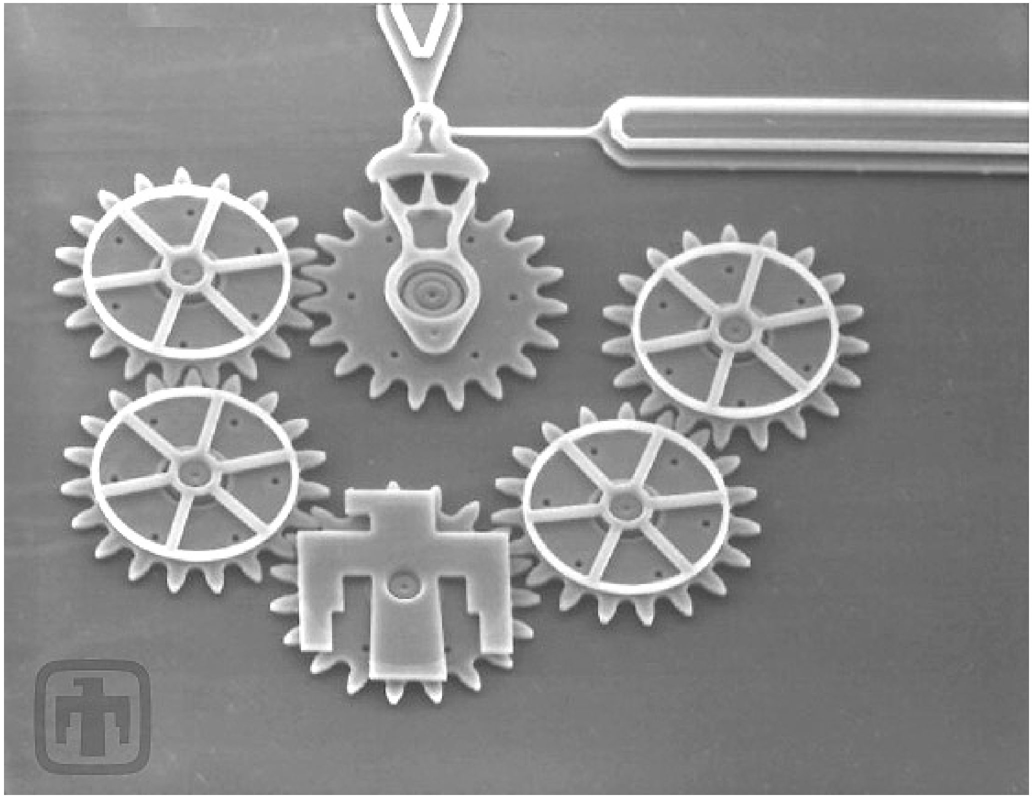
What is MEMS?

- Micro Electro Mechanical Systems
- Sensors
- Actuators
- Motors



Power Sources

- How do we run these devices?
  - External power
  - Fuel Cells
  - Chemical Batteries
  - Fossil Fuels
  - Radioisotopes

Nuclear Batteries for MEMS

- Radioisotopes have been used for power for a long time (space, pacemakers)
- Advantages are long life (decades without refueling)
- …and high energy density

Comparison

- Consider 1 mg for power source

Source	Energy Content (mW-hr)
Chemical Battery (Li-ion)	0.3
Fuel Cell (methanol, 50%)	3
210-Po (5% - 4 years)	3000
3-H (5% - 4 years)	500

Isotope Selection

- Type of radiation
  - Alpha
  - Beta
- Half-Life
  - Long -> Long battery life
  - Short -> Higher power
- Avoid gammas in the decay chain
- Energy of particles

Isotope Selection

Isotope	Average energy	Half life	Specific activity	Specific Power	Estimated Range in Cu
	(KeV)	(year)	(Ci/g)	(W/g)	(microns)
^{63}Ni	17.4	100.2	57	0.006	14
^{32}Si	68.8	172.1	65	0.03	107
^{90}Sr	195.8	28.8	138	0.16	332
^{106}Ru	10.03	1.06	3300	0.0002	5
^{3}H	5.7	12.3	9664	32.5	3
^{210}Po	5304.3	0.38	4493	137	0.5
^{32}P	694.9	0.04	285700	1.18	1344

Incorporation of Sources

- Three Ways
  - Activation in reactor
  - Addition of radioactive liquid to device
  - Addition of radioactive solid to device
    - Electroless plating of Ni-63
    - H-3 microspheres

Self Absorption in liquid

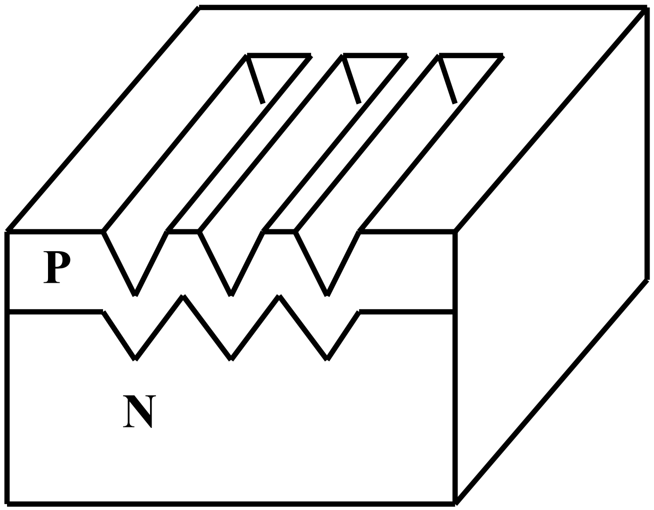
- Liquid sources will have reduced efficiency due to beta absorption
- We measured power using liquid source, then dried and remeasured
- Power increased by 25% after drying
- Activity measurement indicated no evaporation of active species

Tritium from Microspheres

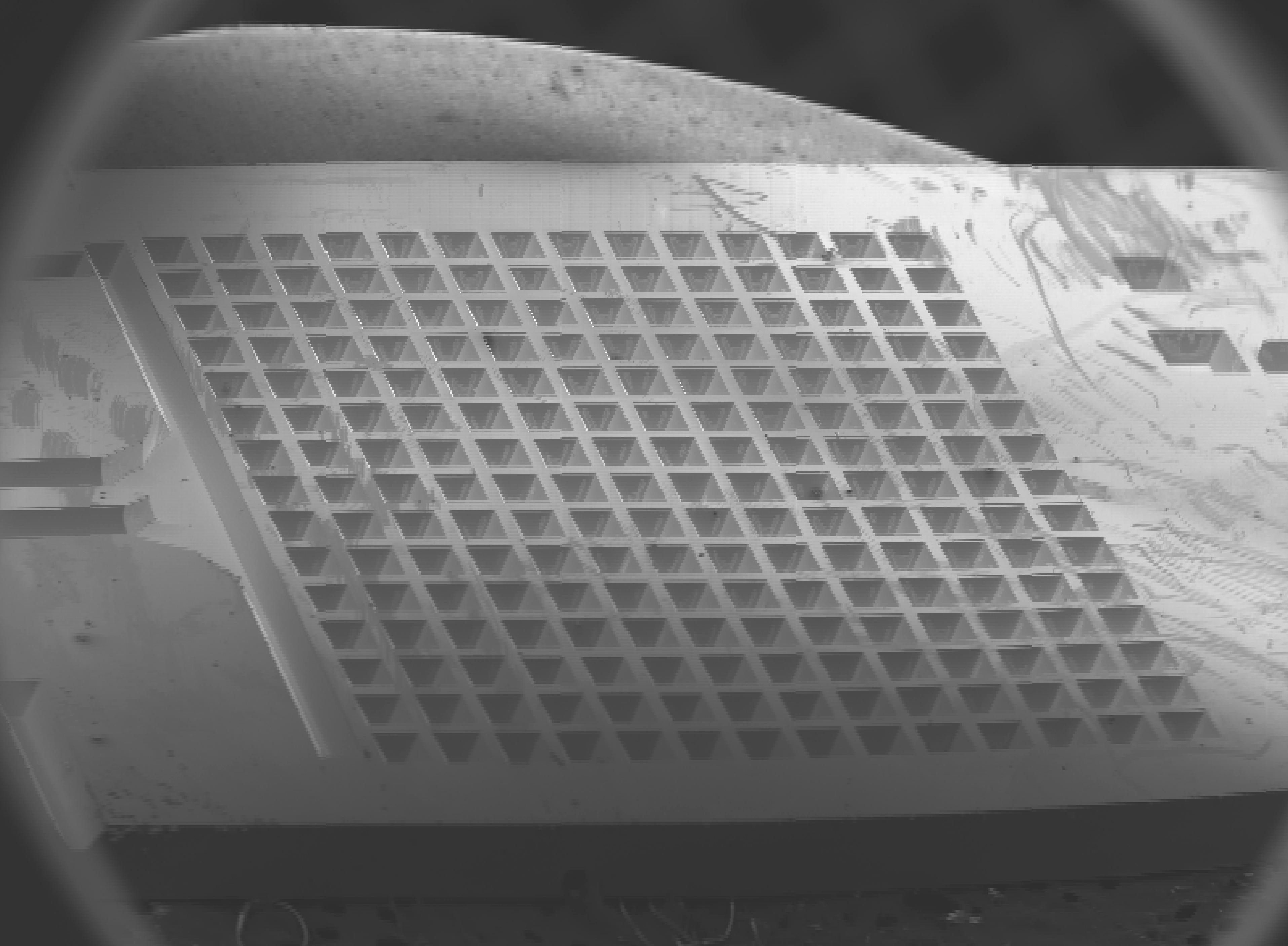
- Glass beads containing Li-6 were irradiated in UW reactor (radius about 20 microns)
- 2 mCi produced in 37 minutes from 0.25 g
- Capsule was filled with water to prevent heating
- Maximum temperature estimated to be 360 C (worst case)
- Beads were then placed in diode

Junction Type Battery

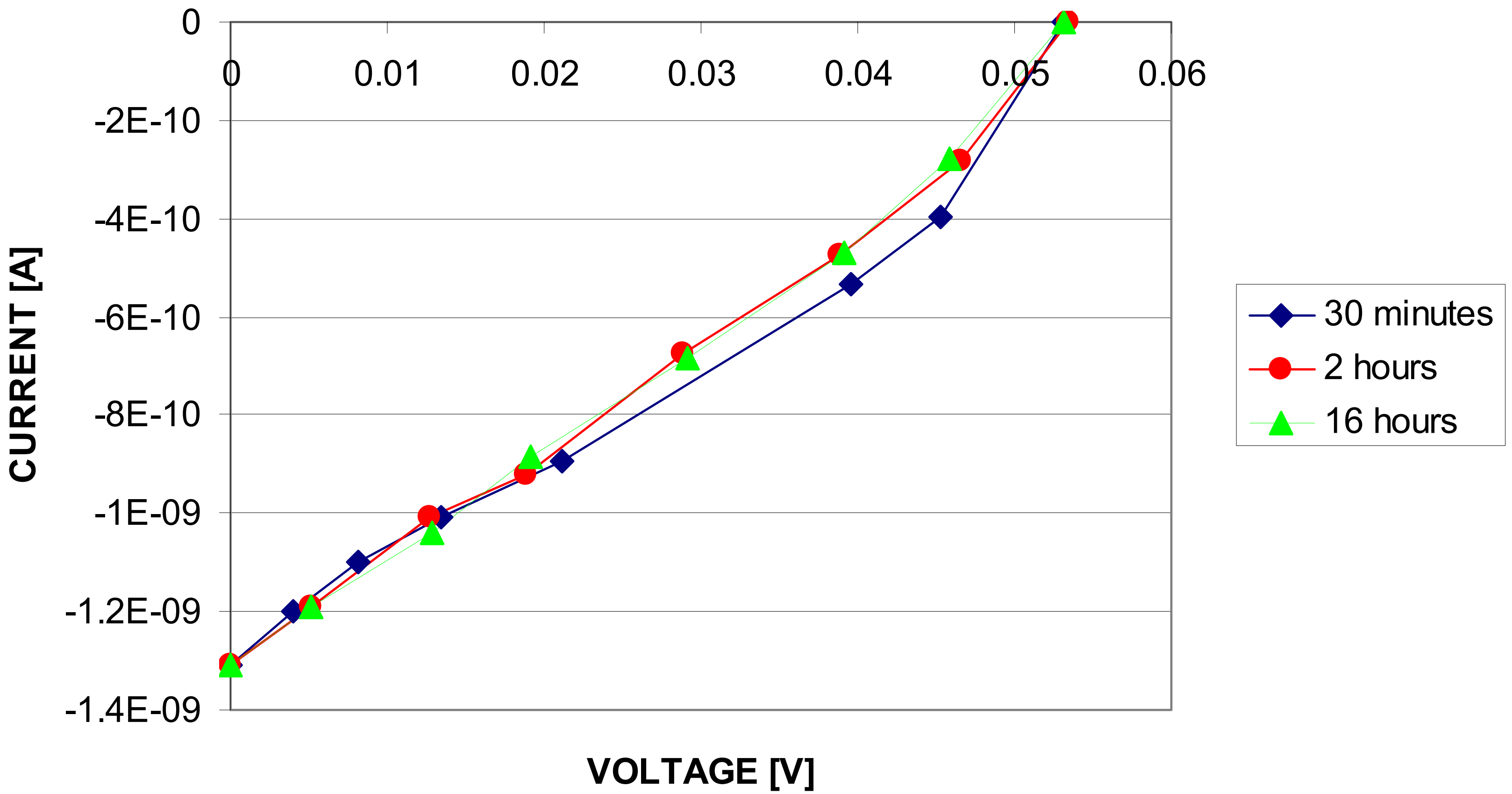
- Energy from radiation used to create ion-hole pair in the junction.
- Excessive energy might damage the junction (> 250KeV)
- Current proportional to contact area



•13 micromachined channels (55% more than planar)
• 8 µl of liquid ^{63}Ni (64 µCi)

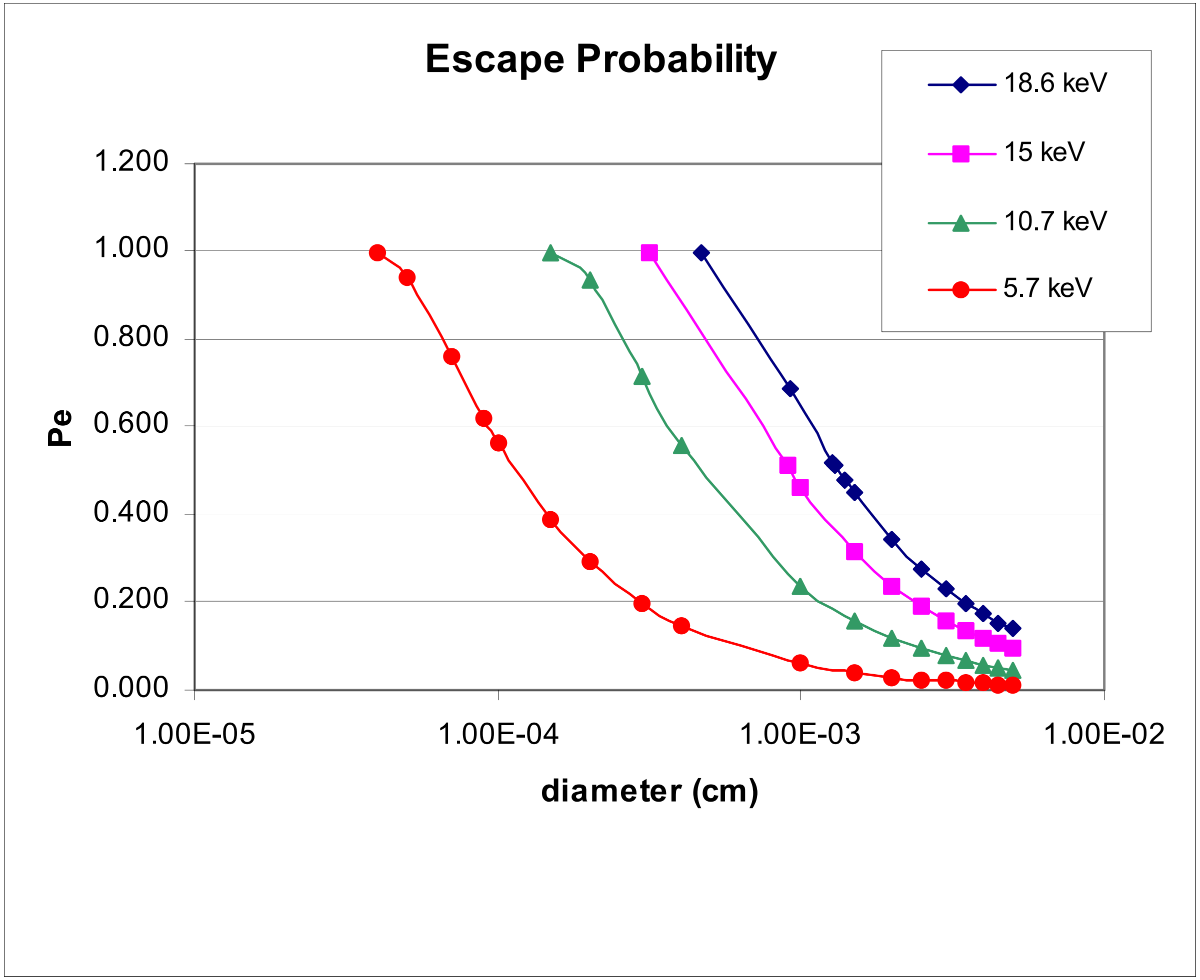


Performance



Beads Must Be Small Enough to Avoid Significant Absorption

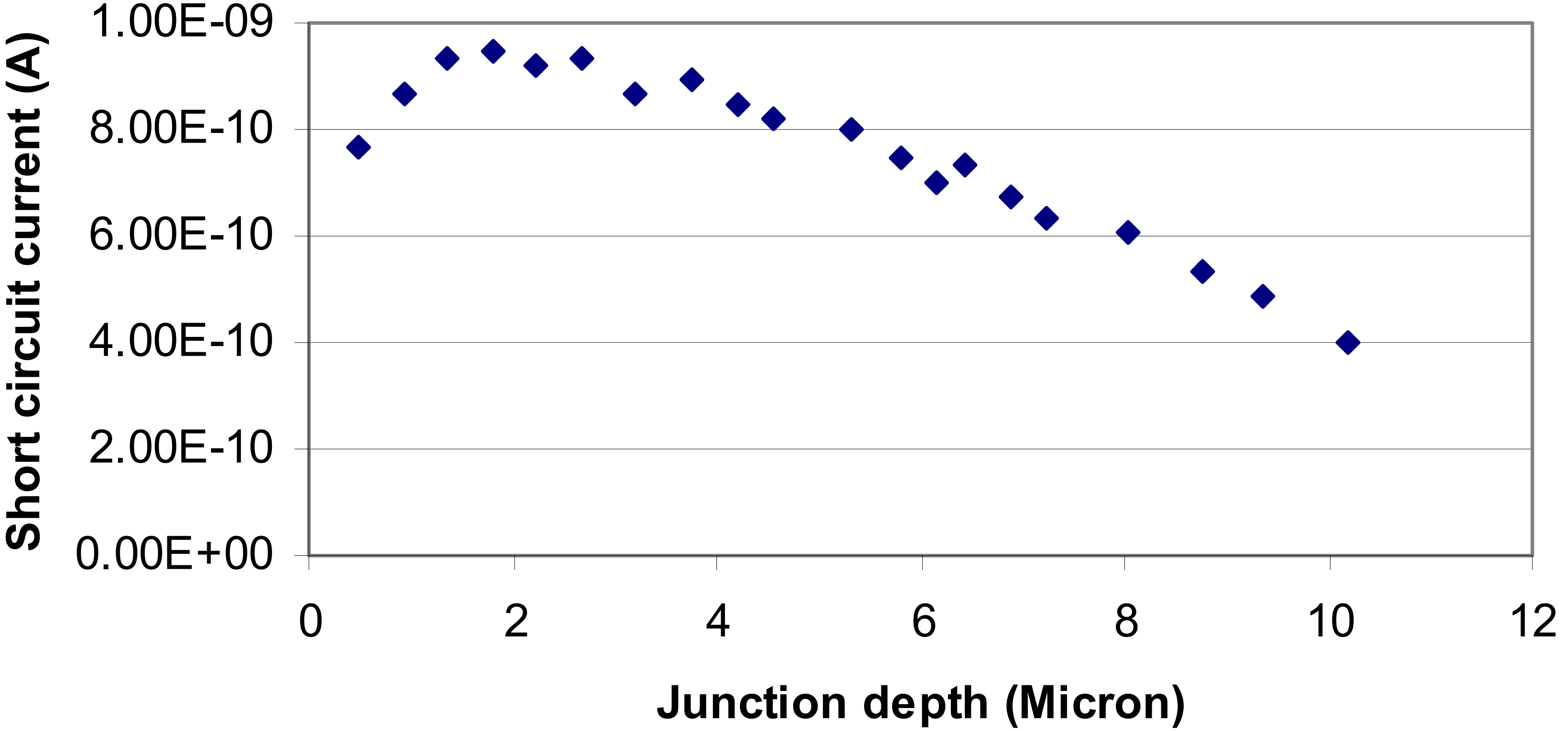
Sphere with uniform production of betas



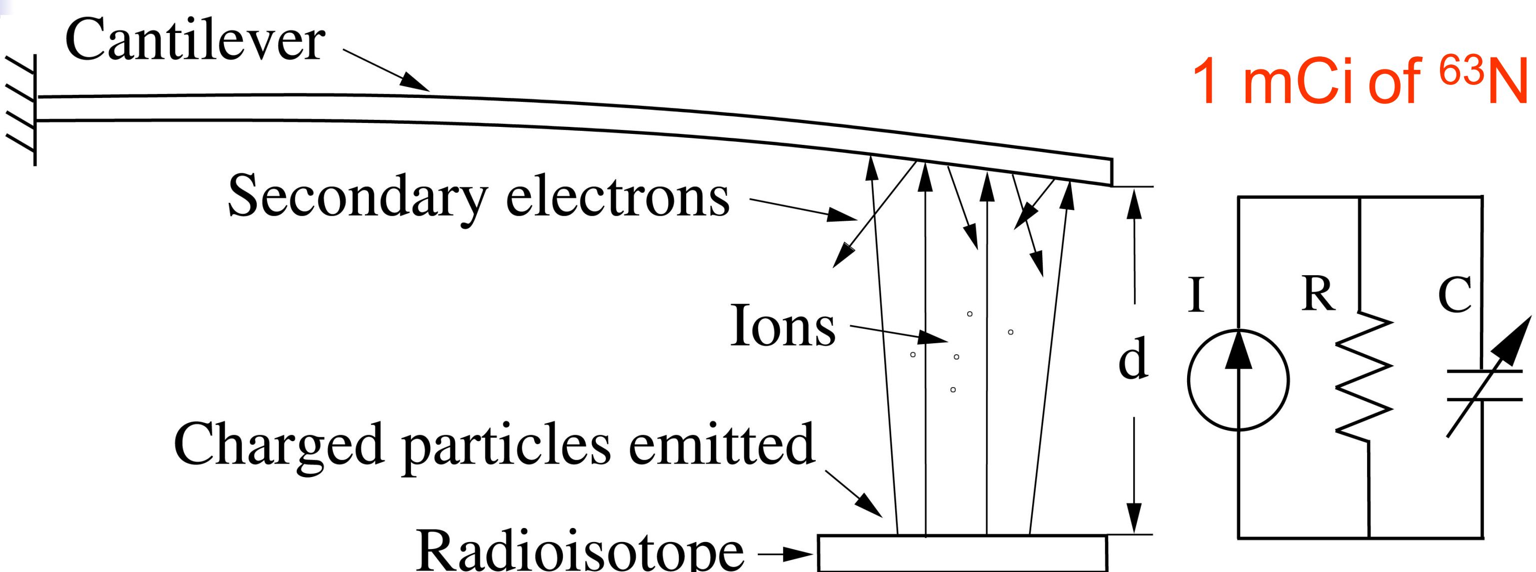
Optimization of Diode

- If junction is too deep, most particles will stop short
- If too shallow, performance will be poor
- We conducted test of range of depths (0.5 to 10 microns deep)
- Voltage depends on diode characteristics, so current is key variable
- Junction width ~ 1 micron
- Result is isotope dependent (and diode)

Optimum depth ~ 2 microns

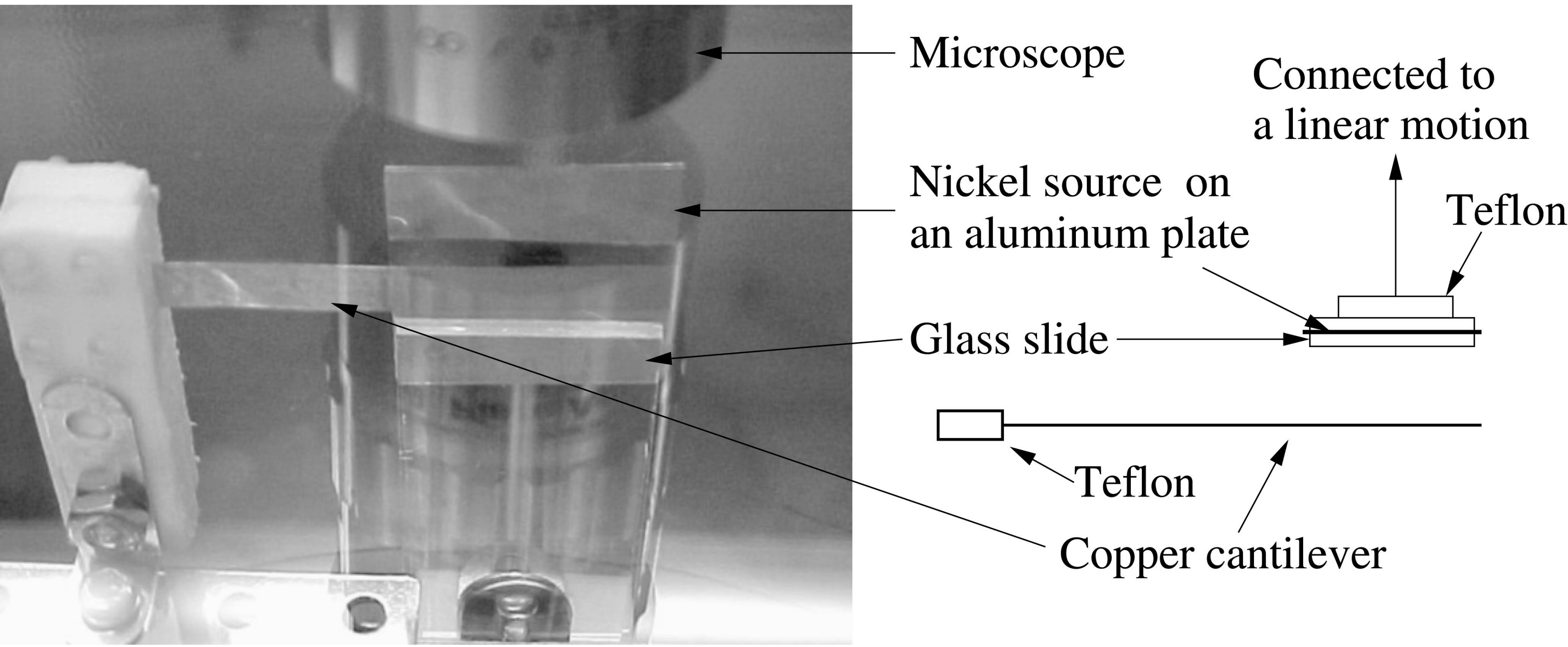


Self-Reciprocating Cantilever



- Accumulated charge created by ionizing radiation leads to attractive force.
- Beam discharges on contact.
- Resulting movement is periodic.

Photograph


Microscope
Connected to
a linear motion
Nickel source on
an aluminum plate
Teflon
Glass slide
Teflon
Copper cantilever

Modeling

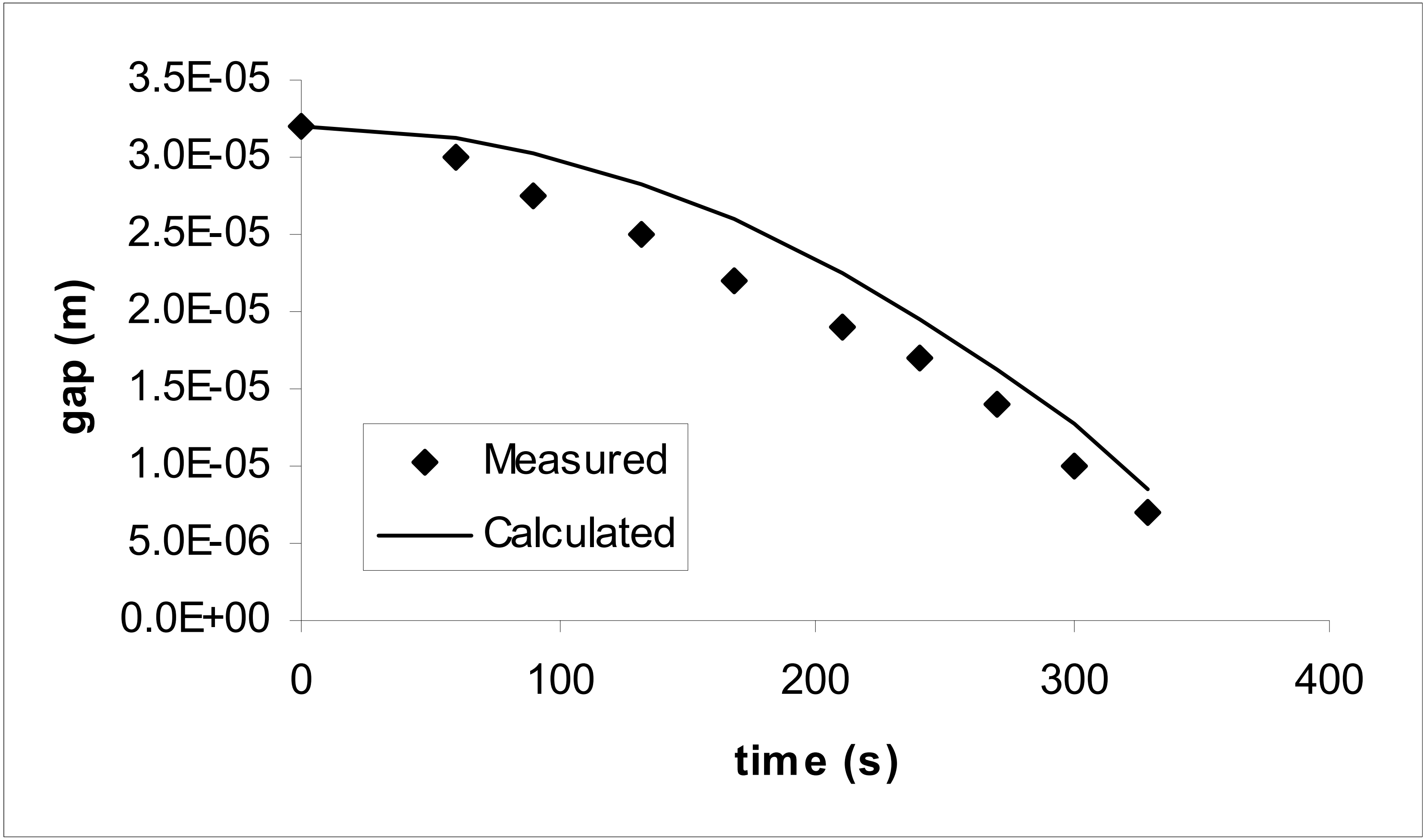
- The charge collecting process is governed by:

$$\varepsilon_0 \frac{d}{dt}\left(\frac{V}{d}\right) = \alpha \frac{I}{A} - \frac{V}{RA}$$

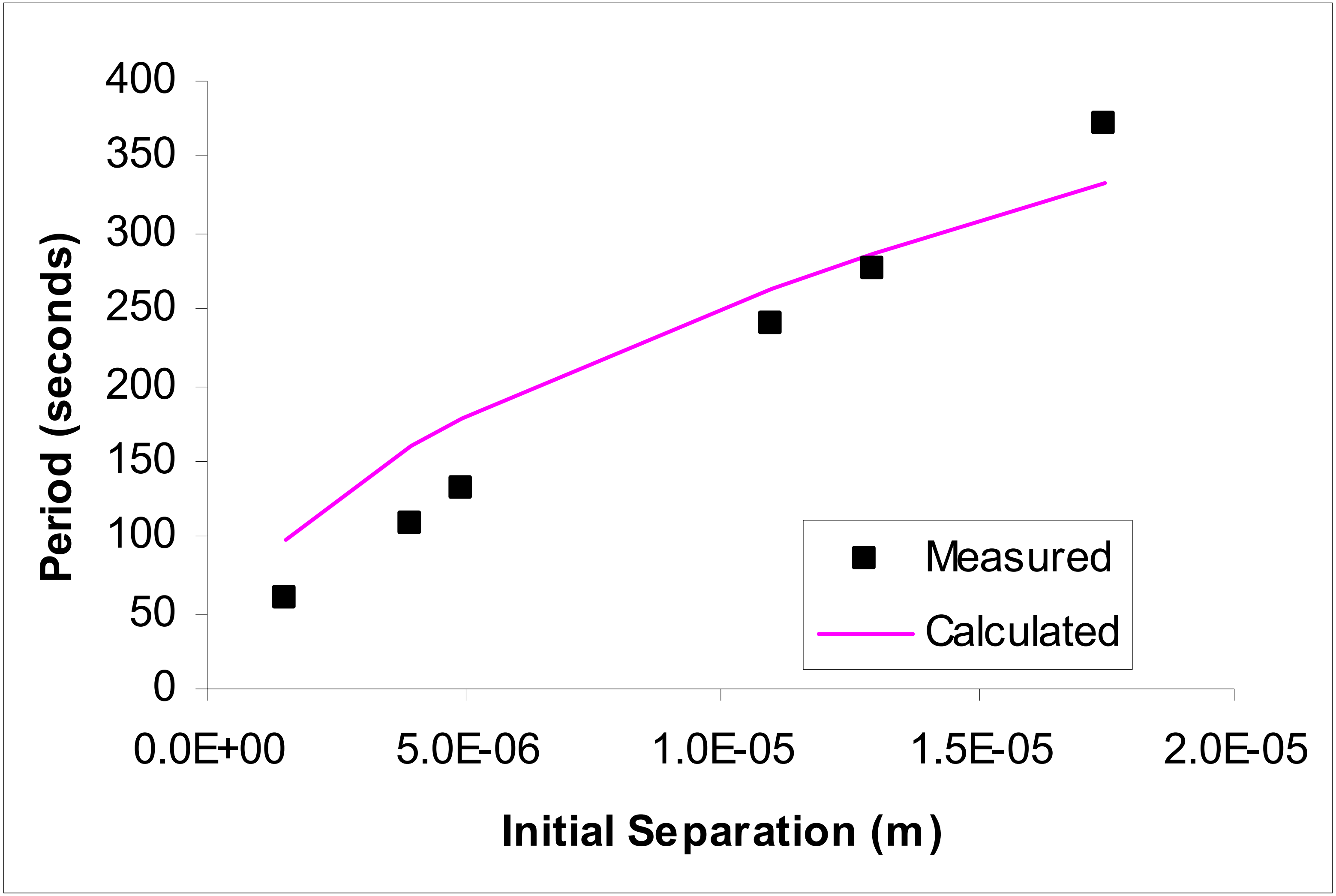
- Beam stiffness k gives:

$$k(d_0 - d) = \frac{\varepsilon_0 A V^2}{d^2}$$

Comparison to Experiment



Comparison of Time to Contact



Conclusions

- Radioisotopes can provide practical power for MEMS
- Primary advantage is long life