

Metrology at the micro and nano scale

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The Role of Metrology



 Predicted market growth: \$605 million (2010) → \$4.4 billion (2020) (IDTechEx Energy Harvesting and Storage for Electronic Devices 2010-2020)

- Accurate, standardised measurement:
 - Stimulates development and innovation
 - Develops market acceptance of EH devices
 - Allows producers to provide meaningful product specifications

If we cant measure it, we can't control it





EMRP Project





Metrology for energy harvesting

European Metrology Research Programme

Developing 'traceable' measurement methods for EH technologies such as thermoelectric and vibrational harvesting devices



The Role of Metrology





www.ti.com/energyharvesting.





EH MEMS structures



LNE





Steve Dunn QMUL















MEMS cantilever mode shape

Developing three-axis piezoelectric shaker for MEMS device testing









MEMS metrology









Piezo-response Force Microscopy





Thermal Limit



1THz 298 K hf / kT = 0.16

Temperature variation of PZT element in acoustic field

Wooldridge, J.; Blackburn, J.; de Podesta, M.; Stewart, M.; Weaver, P. & Cain, M. Pyroelectric contributions to piezoelectric hydrostatic Berlincourt method Advances in Applied Ceramics, 2010, 109, 143-146

Non-Equilibrium – Reversible and Irreversible Processes



Source Loading





Vibration source resonance with and without the cantilever.







Burnett, T. L.; Weaver, P. M.; Blackburn, J. F.; Stewart, M. & Cain, M. G. Journal of Applied Physics, AIP, 2010, 108, 042001



Schilling, A.; Byrne, D.; Catalan, G.; Webber, K. G.; Genenko, Y. A.; Wu, G. S.; Scott, J. F. & Gregg, J. M. Nano Letters, 2009, 9, 3359-3364



Efficiency and Effectiveness









Efficiency

Or

Effectiveness?



Losses

 ΔV introduces losses





 Flow of charges from piezo capacitor to load capacitor always results in loss of stored energy!

- Charges move from high potential to low potential gaining kinetic energy.
- This is then dissipated as heat/radiation.



Losses





30 element cantilever to investigate the effect of the coverage of the beam with piezoelectric elements





Losses



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The material at the tip contributes extra capacitance (and loss) but little extra charge.



Cumulative charge generated as the area of electrode coverage is increased. ..results in a peak in the energy output with exactly 2/3 of the beam used for collecting





- Metrology is essential to flourishing market and science of energy harvesting
- Measurement at small scales is challenging
 - Materials complexity
 - Thermal effects
 - Losses
 - Source loading
 - Small signal measurement (rectification, capture and storage)



Links & Acknowlegements



- Blog http://tinyurl.com/MetrologyForEH
- Introduction:<u>http://www.iop.org/resources/energy/index.html</u>
- Further information: markys.cain@npl.co.uk
- EPSRC EH Network: http://eh-network.org/steer/
- Funding from UK's National Measurement System
- Resource and support from the Piezo Institute www.piezoinstitute.com
- NPL Multifunctional Materials Group
 Dr's Mark Stewart, Melvin Vopson and Prof. Markys Cain
- EMRP Metrology for Energy Harvesting piezos & thermoeled See http://www.euramet.org/index.php?id=a169jrps



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