Mechanical energy harvesting with piezoelectric nanostructures: Great expectations for autonomous systems

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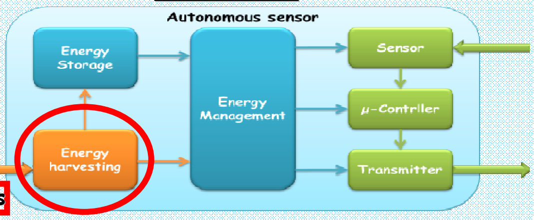
CONTEXT:

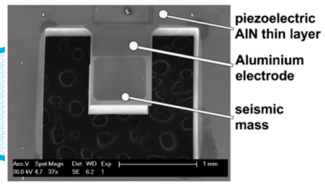
- Light
- Heat
- RF
- Vibrations



Main Applications:
- Autonomous sensors
- Human health, structure health monitoring (buildings, planes…)
- < 200Hz (human, cars)
- > 1kHz (some machines)

Challenges:
- Reduction of size
- Increase the power (energy) density harvested
- IC compatible

MECHANICAL ENERGY HARVESTING WITH MEMS



0.15V, 20μW/cm³, 1.6KHz, Sputtered AlN

M. Marzencki et al., S&A 145-146 2007

Typical devices:
- Resonant cantilever devices at low frequency (< 200Hz)
- Thin film piezomaterials (AlN, PZT) or commercial ceramics
- Power densities : 0.1-43mW/cm³

PIEZO AT NANO

Main Advantages :
- **Integrating multiple nanostructures into non resonant harvester devices is possible**
- **Sensible devices (low mechanical input is sufficient to generate a voltage)**
- **Less material is used, eventually reducing the overall cost of the device**

ZnO

2V, 0.22μW/cm², 11mW/cm³@0.3Hz (200nm wide, 50μm long NW PVD)

G. Zhu et al., Nano Lett. 10 2010

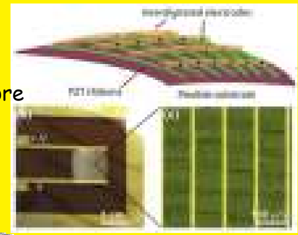
Advantages
- NWs are easy to grown (not expensive)
- Multiple lengths and diameters can be obtained

Inconvenients
- Doping is difficult

PZT

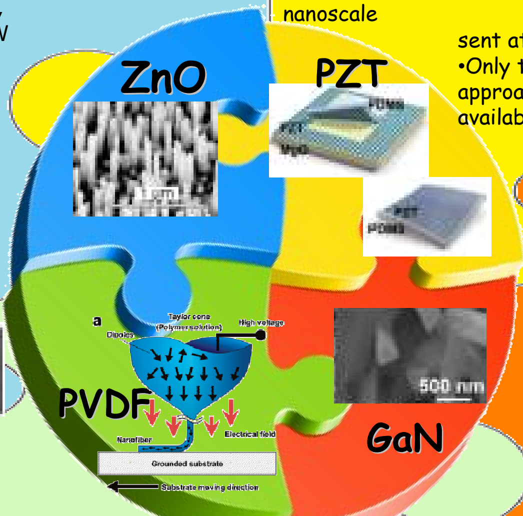
Advantages
- Best piezo coefficient at nanoscale

Inconvenients
- Piezo enhancement effect is not present at nano
- Only top down approaches are available

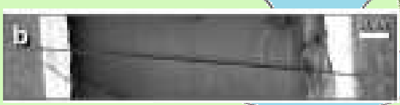


Y. Qi et al., Energy Environ. Sci . 3 2010

0.25V, 10nW/cm²@3Hz (500nm thick, 5μm wide)



PVDF



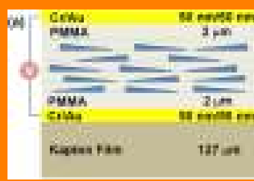
C. Chang et al., Nano. lett. 10 2010

13mV, 26pW/wire@4Hz – (500nm-6.5μm wide, 100-600μm long - Electrospinning)

Advantages
- NWs with high aspect ratio can be easily fabricated

Inconvenients
- Integration of large numbers of NWs is difficult

GaN



L. Lin et al., Nanotechnology 22 2011

1.2V, 0.16μA/cm²@0.5Hz – (100-500nm wide, 10-20μm long - VLS)

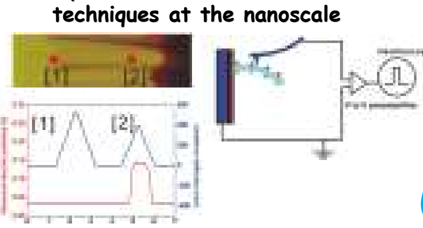
Advantages
- Compatible with Si technology
- can be doped(n, p) , heterostructured
- Piezo properties can be improved

WHAT ABOUT THE FUTURE?

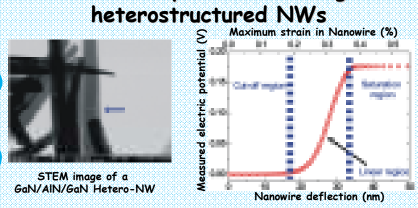
Actual piezoelectric coefficients (d_{33}) at the nanoscale compared to bulk (from the literature)

Material	d_{33} [pm/V] Theoretical (nanoscale)	Experimental (nanoscale)	Experimental (bulk)
PVDF	N/A	-38	-25
PZT	N/A	101	650
ZnO	168.2	14-26.7	9.93
GaN	65.8	12.8	1.86

Development of new characterization techniques at the nanoscale



Further improvements using heterostructured NWs



X. Xu et al., Nanotechnology 22 2011
Piezoelectric coefficient improved up to 9x using GaN/AlN heterostructured NW

CONCLUSION

- Nanowires present enhanced properties: **high piezoelectricity and reduced stiffness**
- Integrated NWs are a promising solution to harvest energy at **any frequency or random mechanical input**
- Harvested power densities using piezo nanostructures are becoming comparable to MEMS piezo harvesters
- Using **heterostructured NWs** can further increase the harvested energy density

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