CEAE
Center of Excellence on Alternative Energy

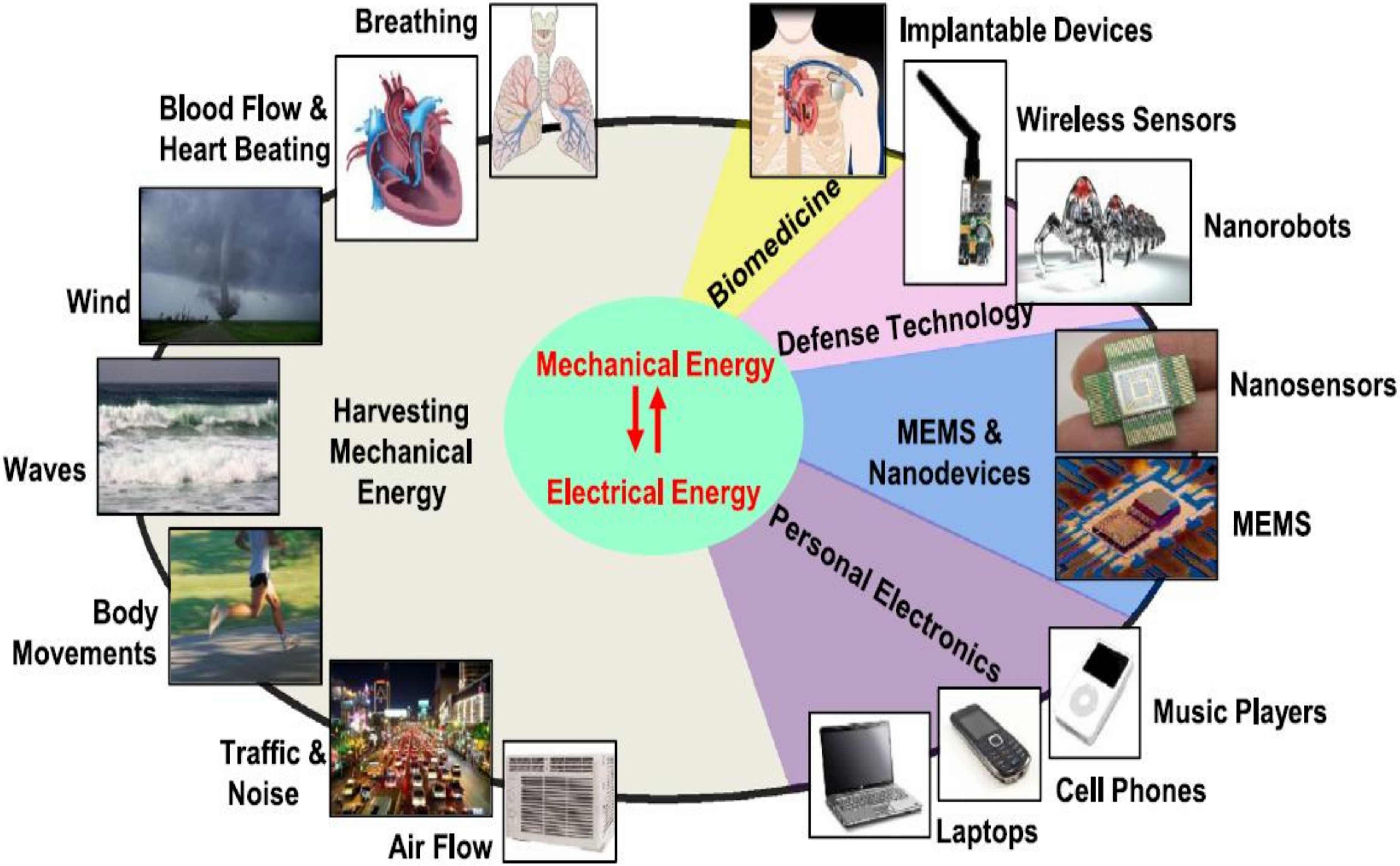
PERL
PIEZOELECTRIC
Research Laboratory

# The ASEAN on Thermoelectric Device Workshop 2018

# เทคโนโลยีพิโซอิเล็กทริก ประโยชน์จากพลังงานกล


ดร.หรรษกร วรรธนะสาร

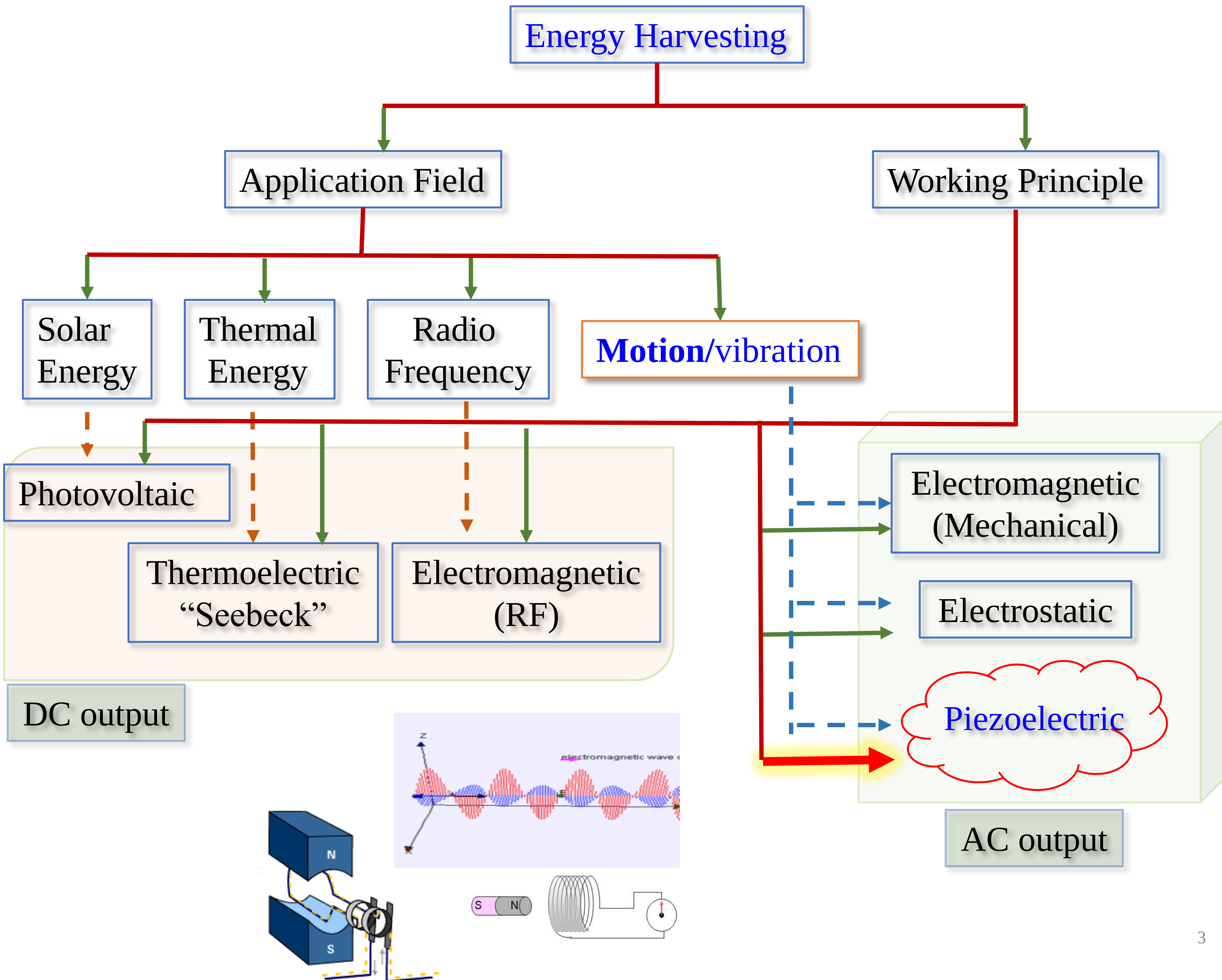
สาขาวิชาฟิสิกส์ คณะวิทยาศาสตร์และเทคโนโลยี

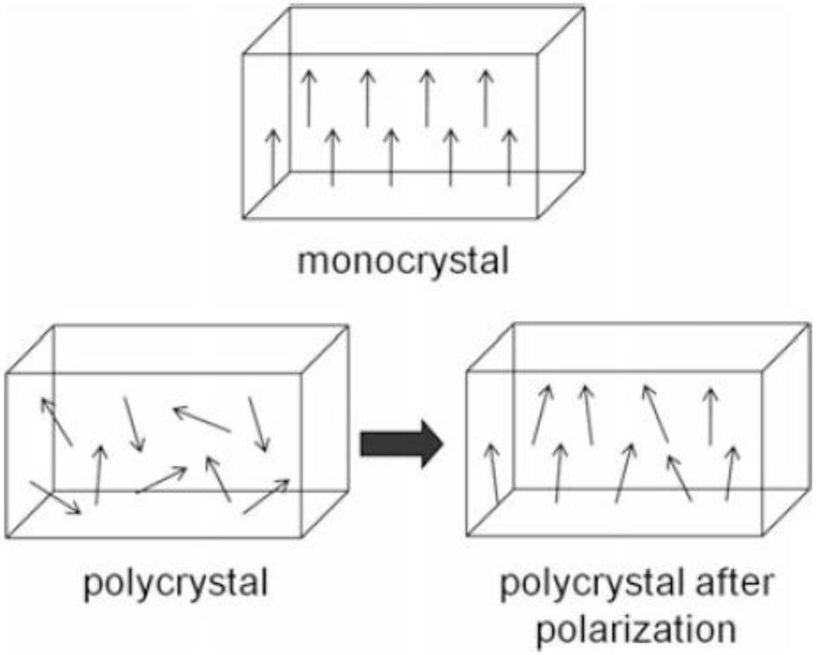



Possible sources of energy for harvesting (left) and opportunities use of this energy in sensing and actuation (right) that can be considered for flexible/bendable devices.

Canan Dagdeviren, Pauline Joe b, Ozlem L. Tuzmanc, Kwi-Il Park, Keon Jae Lee, Yan Shi, Yonggang Huang, John A. Rogers, Recent progress in flexible and stretchable piezoelectric devices for mechanical energy harvesting, sensing and actuation. Extreme Mechanics Letters 9 (2016) 269–281.

# Main energy harvesting technologies.






Polycrystal.

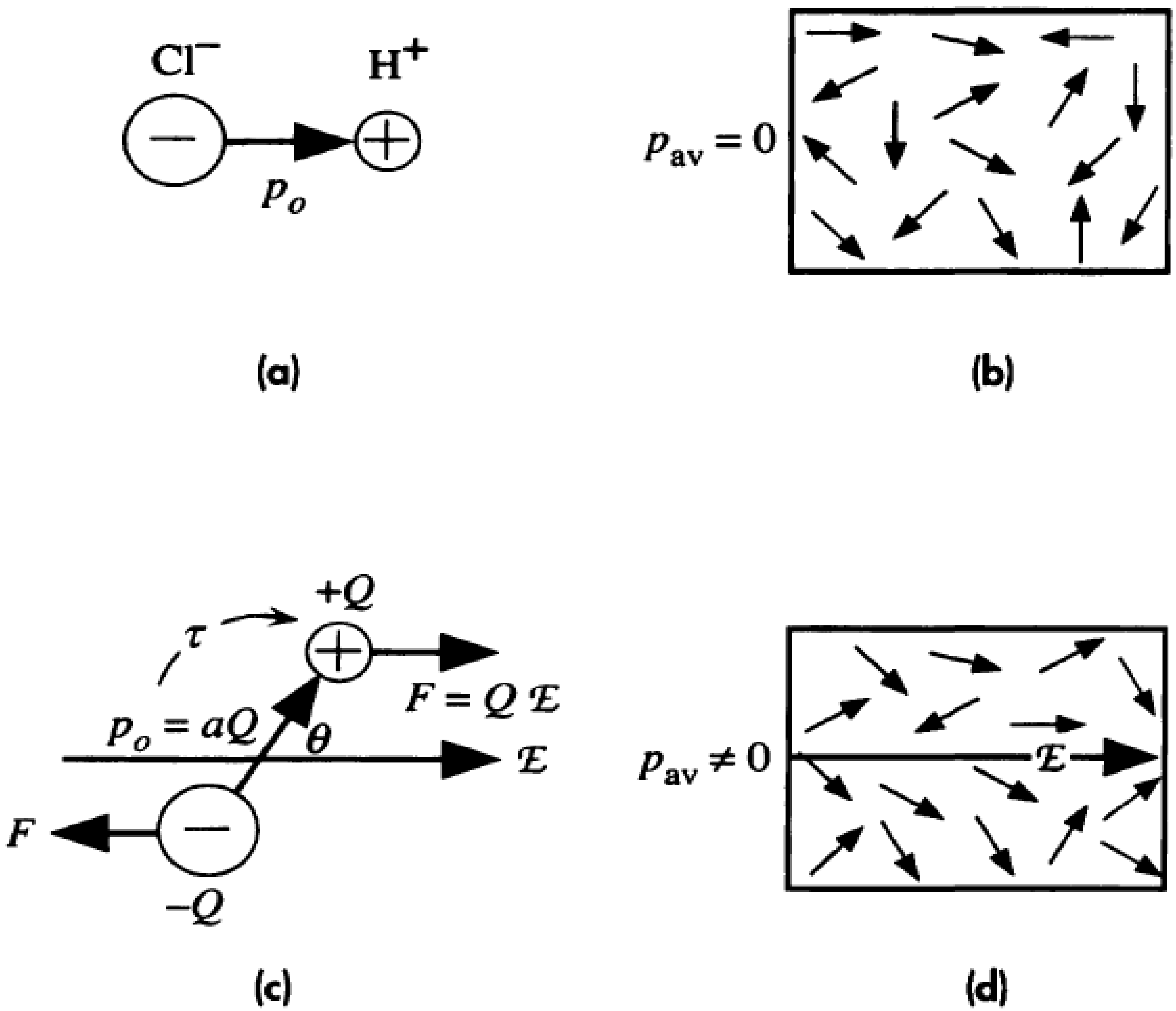
(a) Polarizations; (b) Surviving Polarity.


**Dipoles are well aligned in monocrystal, but random in polycrystal.**

**The dipoles in polycrystal can be aligned through polarization**

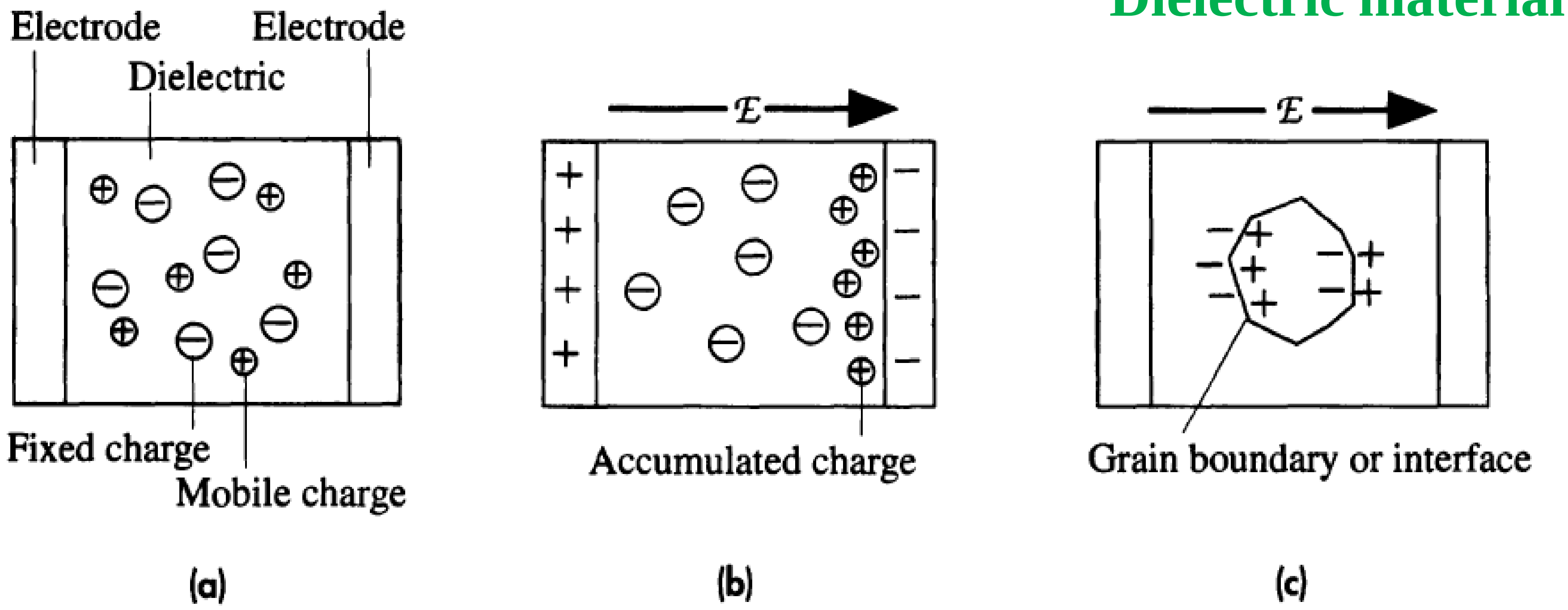
Jeong-Yeol Yoon, Introduction to Biosensors From Electric Circuits to Immunosensors. Springer New York Heidelberg Dordrecht London (2013)

# Dipole



Cl⁻
H⁺
$p_o$
$p_{av} = 0$
(a)
(b)
+Q
τ
$F = Q\mathcal{E}$
$p_o = aQ$
θ
$\mathcal{E}$
F
−Q
$p_{av} \neq 0$
$\mathcal{E}$
(c)
(d)

# Dielectric material




(a) A crystal with equal number of mobile positive ions and fixed negative ions. In the absence of a field, there is no net separation between all the positive charges and all negative charges.

(b) In the presence of and applied field, the mobile positive ions migrate toward the negative charges and positive charges in the dielectric. The dielectric therefore exhibits interfacial polarization.

(c) Grain boundaries and interface between different materials frequently give rise to interfacial polarization.

$$C = \frac{\varepsilon_0 \varepsilon_r A}{t}$$

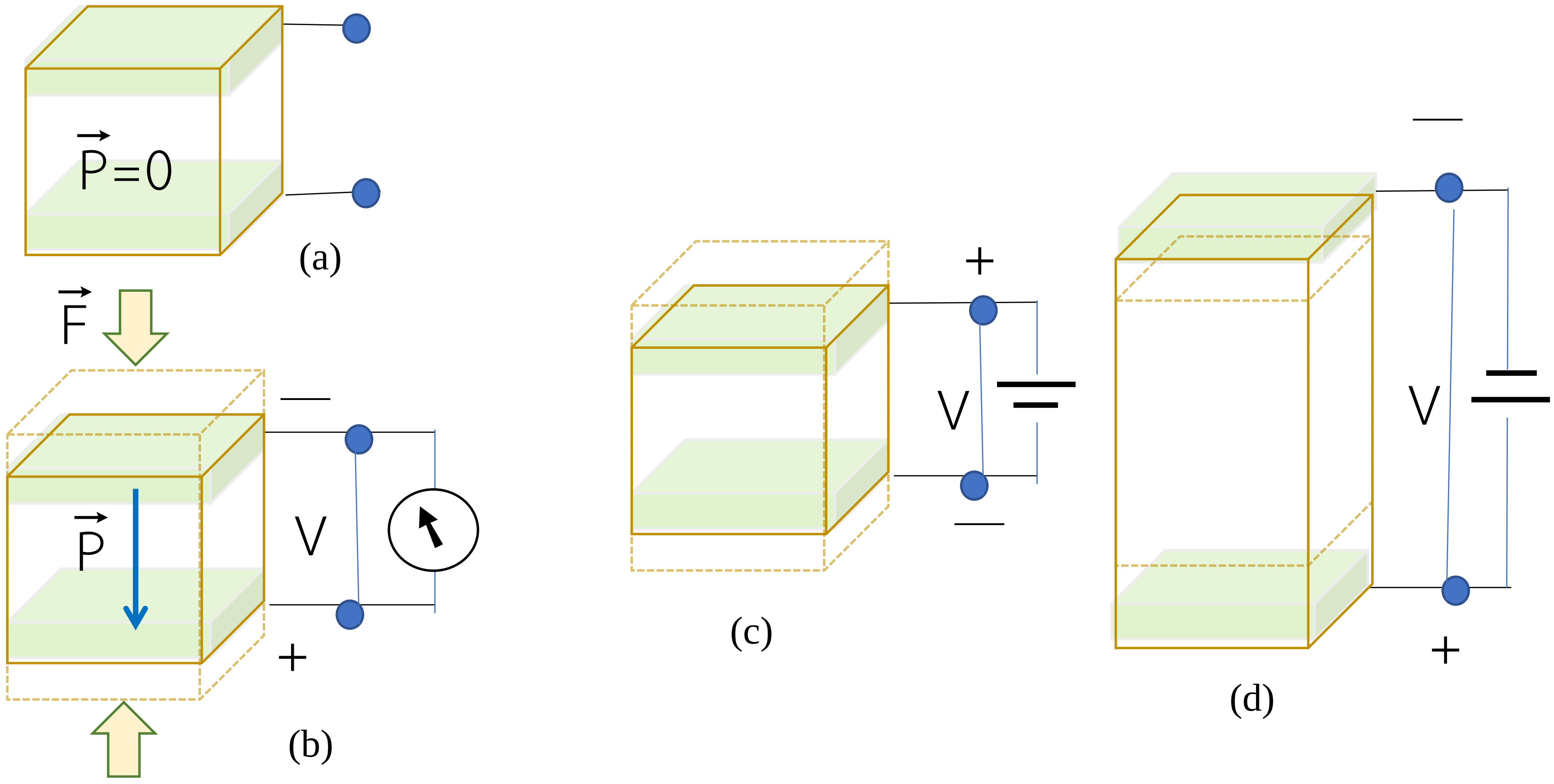
$\varepsilon_r$ **the relative permittivity or dielectric constant**

$\varepsilon_0$ the vacuum permittivity

$A$ the area

$t$ the thickness

$C$ the capacitance




The piezoelectric effect

**(a) A piezoelectric crystal with no applied stress or field**

**(b) The crystal is strained by applied force that induces polarization in the crystal and generates surface charges**

**(c) An applied field causes the crystal to become strained. In this case the field compress the crystal**

**(d) The strain changes direction with the applied field and now the crystal is extended**

# Electromechanical coupling factor *k*

***direct piezoelectric effect***

$$P_i = d_{ij} X_j$$

***converse piezoelectric effect***

$$X_j = d_{ij} E_j$$

$$i = 1, 2, 3; \quad j = 1, 2, \ldots, 6$$

$$g = \frac{d}{\varepsilon_r}$$

$$k^2 = \frac{\text{Electrical energy converted to mechanical energy}}{\text{Input of electrical energy}}$$

$$k^2 = \frac{\text{Electrical energy converted to electrical energy}}{\text{Input of mechanical energy}}$$

$$k^2 = 1 - \frac{f_s^2}{f_a^2}$$

***The efficiency of energy conversion,***

$$\text{efficiency} \quad \eta = \frac{Qk^2}{(1-k^2) + Qk^2}$$

*Mechanical quality factor,* $Q_m$

$$Q = \frac{1}{2\pi \, \Delta f \, RC}$$

$P_i$ **the induce polarization** along some *i* direction

$X_j$ the applied mechanical stress along some *j* direction

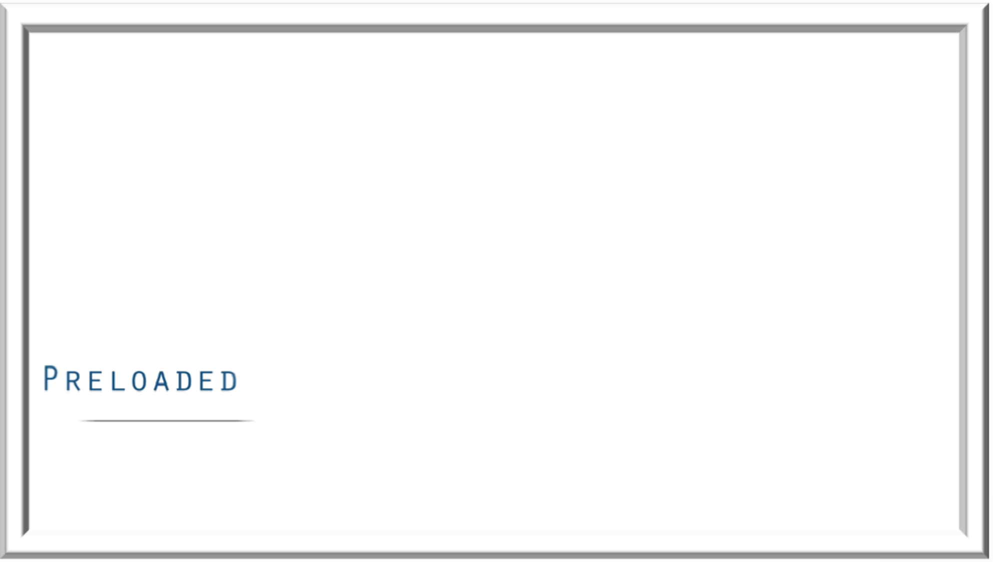
$d_{ij}$ **the piezoelectric coefficients**

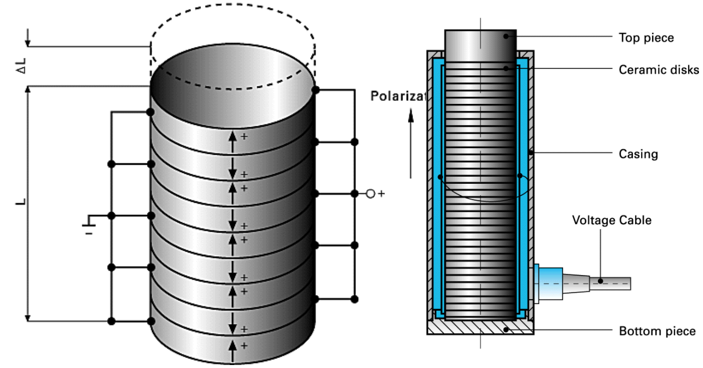
$S_j$ the induce strain

$E_i$ **the applied electric field**

$g$ the piezoelectric voltage constant

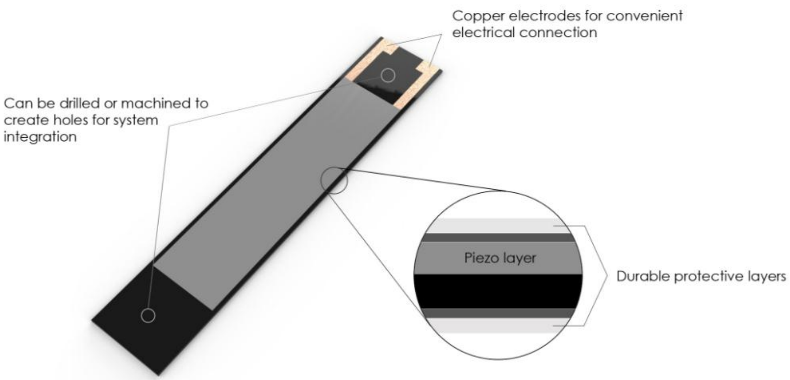
$f_s$ **the resonant frequency** $f_a$ **antiresonant frequency**

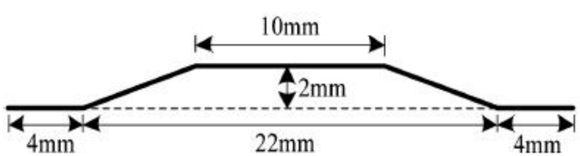


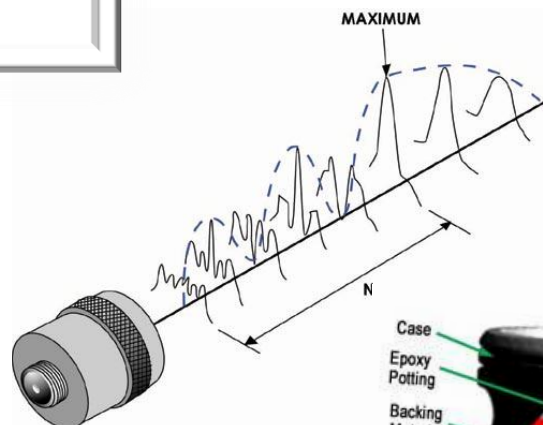



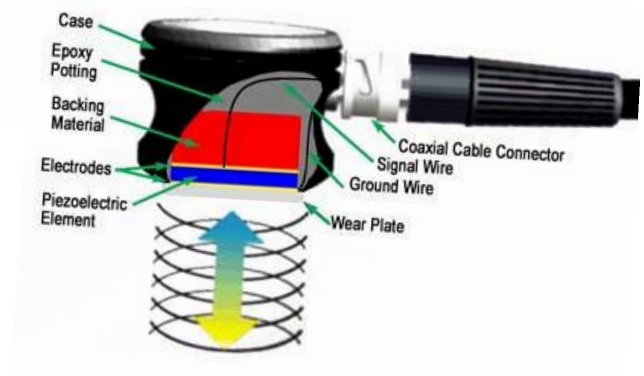

# Piezoelectric actuator

# Piezoelectric monomorph



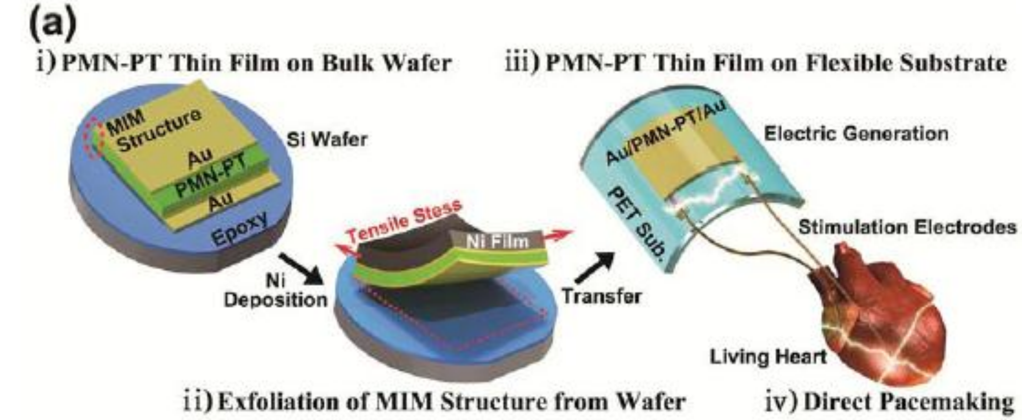



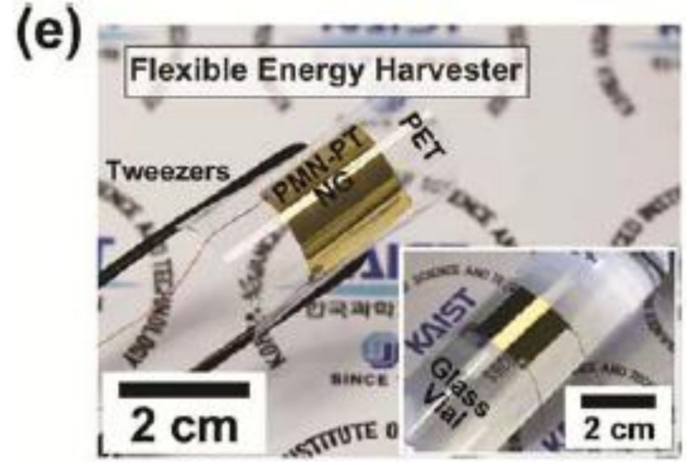

# Piezoelectric transducer

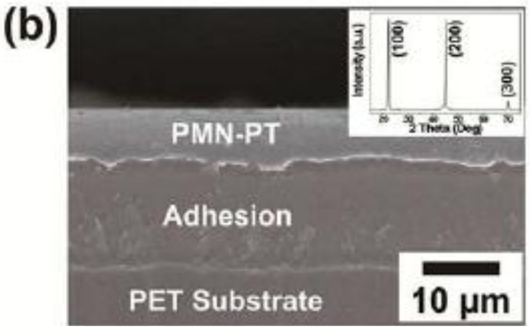
http://www.ultrasonic
resonators.org/design/transducers/transducer_design.html
https://www.ndeed.org/EducationResources/CommunityCollege/Ultrasonics/EquipmentTrans/characteristicspt.htm

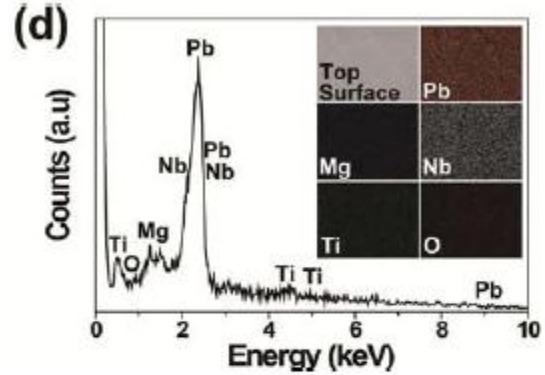


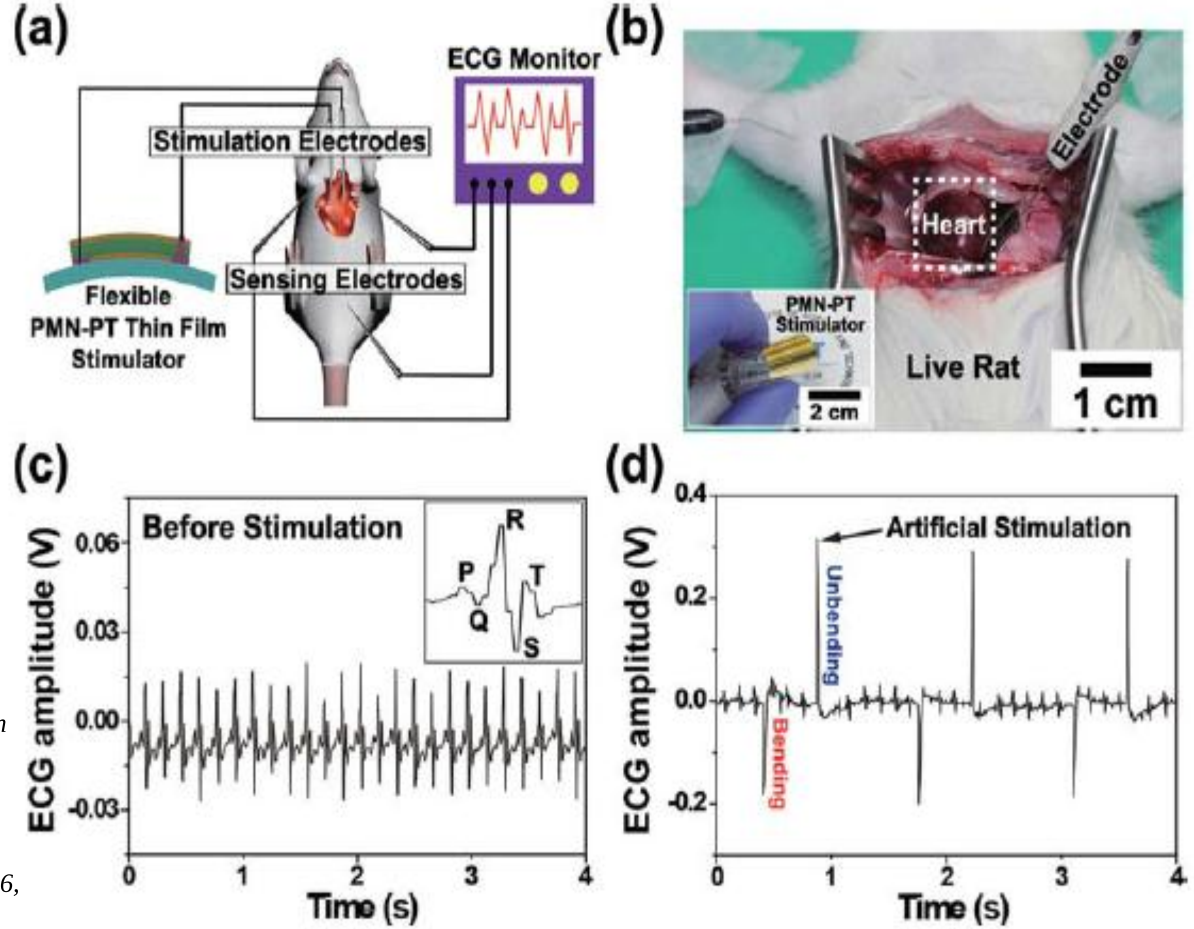
Hongduo ZHAO, Jianming LING* and Jian YU. Journal of the Ceramic Society of Japan 120 [8] 317-323 2012



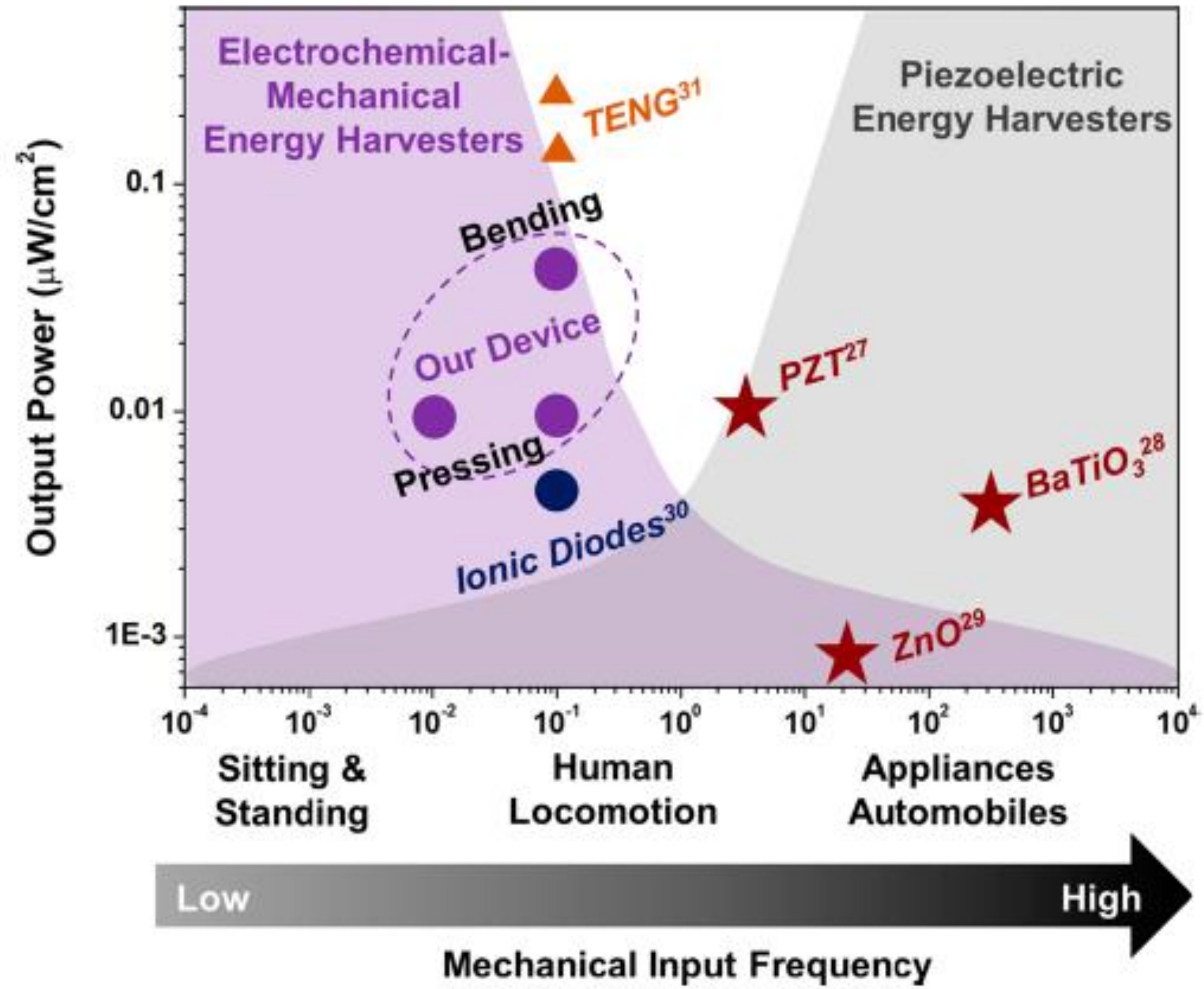



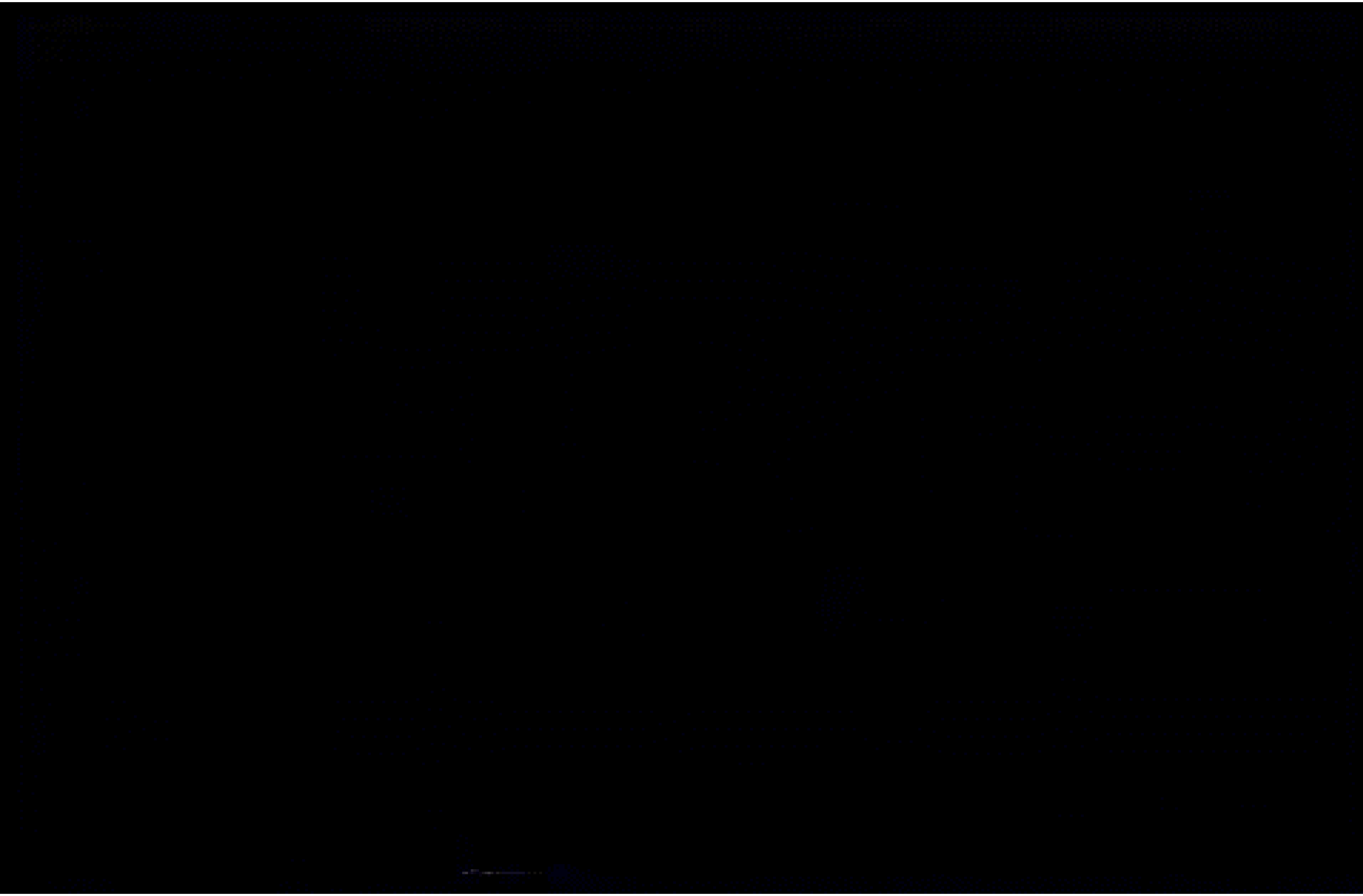



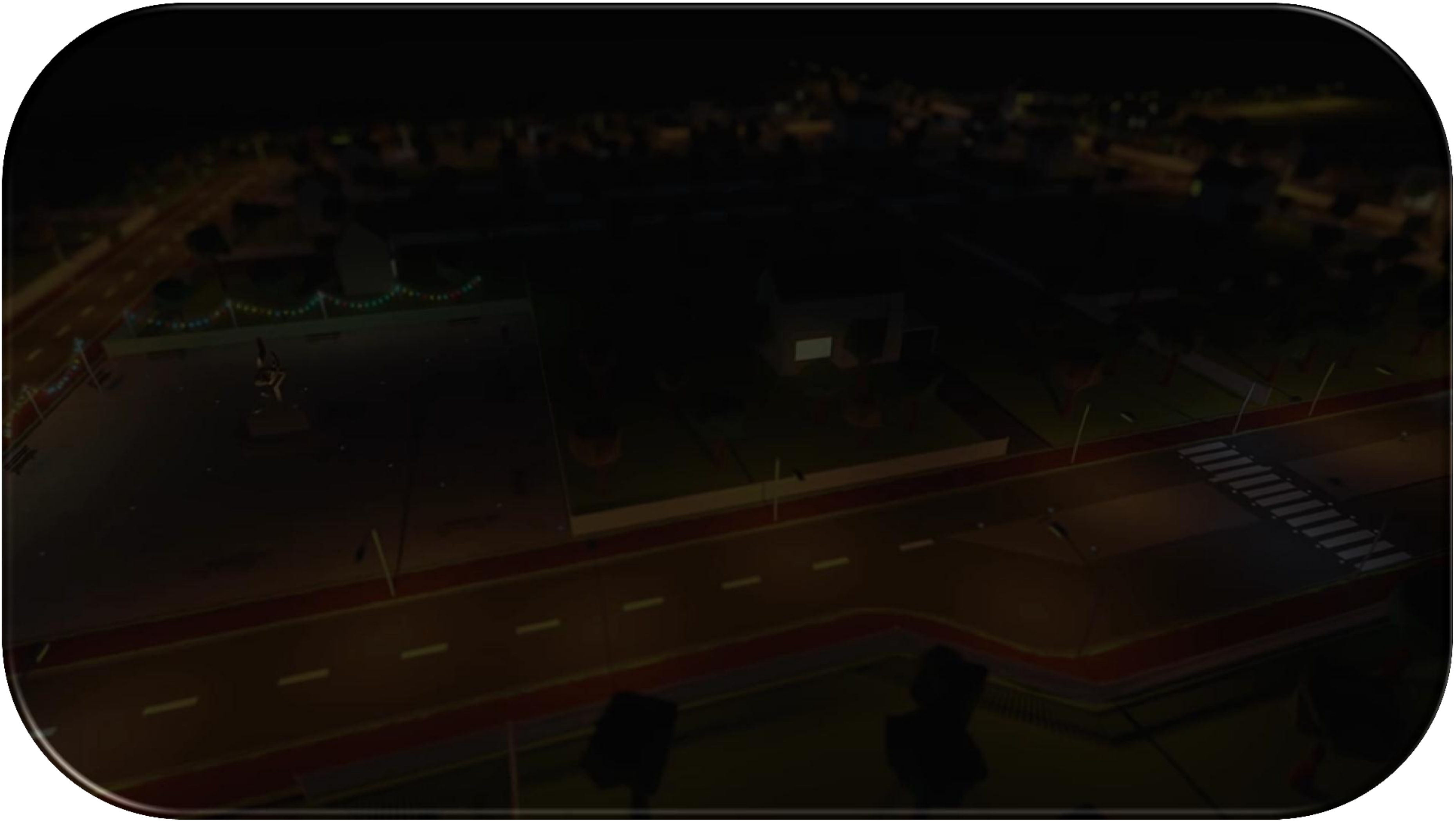

*Geon-Tae Hwang , Hyewon Park , Jeong-Ho Lee , SeKwon Oh , Kwi-Il Park , Myunghwan Byun , Hyelim Park , Gun Ahn , Chang Kyu Jeong , Kwangsoo No , HyukSang Kwon , Sang-Goo Lee , Boyoung Joung , and Keon Jae Lee. Self-Powered Cardiac Pacemaker Enabled by Flexible Single Crystalline PMN-PT Piezoelectric Energy Harvester. Adv. Mater. 2014, 26, 4880–4887*

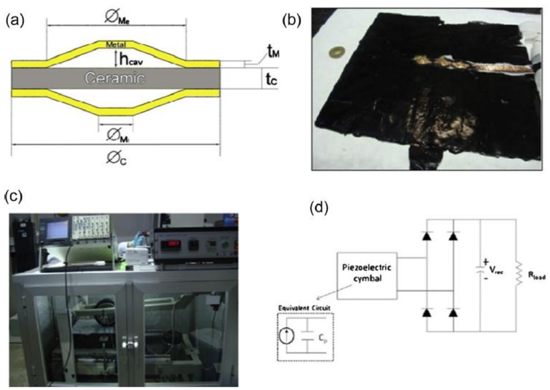



Shaded regions indicate the fall-off of **energy harvesting capability at low frequencies outside of the range of traditional harvesting routes (left)** and at **high frequencies outside of the range of electrochemical harvesters (right).**

Nitin Muralidharan, Mengya Li, Rachel E. Carter, Nicholas Galioto, and Cary L. Pint . Ultralow Frequency Electrochemical−Mechanical Strain Energy Harvester Using 2D Black Phosphorus Nanosheets. ACS Energy Lett. 2017, 2, 1797−1803



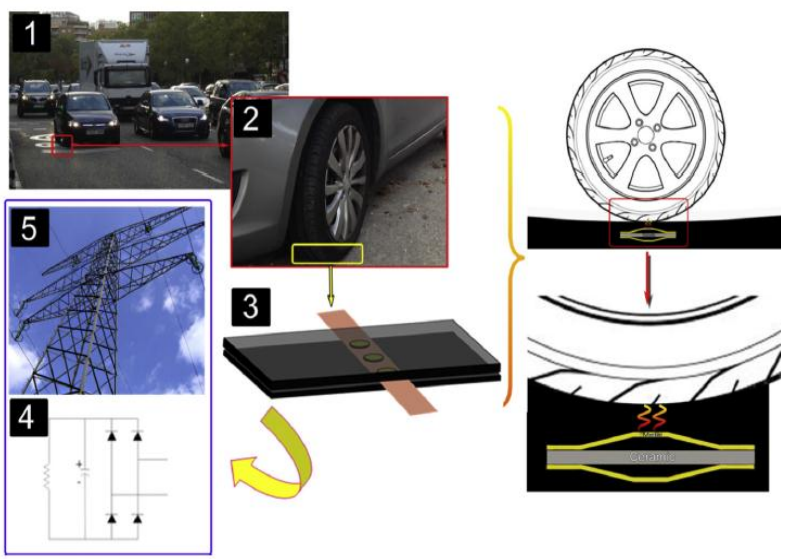


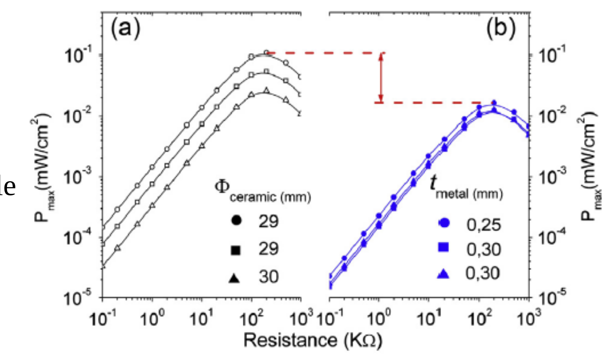


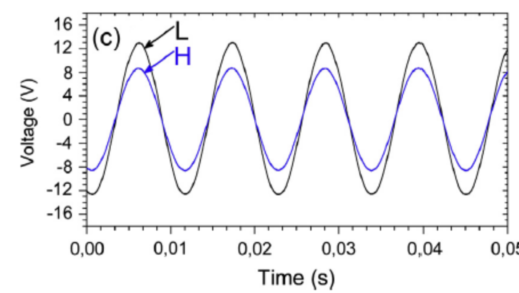

| | | Noliac | PI |
|---|---|---|---|
| Diameter (mm) | $d$ | 30 | 29 |
| Relative dielectric constant | $\varepsilon_{33}{}^{T}/\varepsilon_0$ | 1850 | 1250 |
| Dielectric loss factor | $\tan\delta$ $(10^{-4})$ | 190 | 50 |
| Coupling factors | $k_p$ | 0.65 | 0.55 |
| | $k_t$ | 0.51 | 0.48 |
| Piezoelectric charge constants $(10^{-12}$ C/N) | $-d_{31}$ | 195 | 140 |
| | $d_{33}$ | 460 | 310 |
| Piezoelectric voltage constants $(10^{-3}$ V m/N) | $-g_{31}$ | 13 | 13.1 |
| | $g_{33}$ | 27 | 29 |
| Mechanical quality factor | $Q_m$ | 80 | 1500 |
| Curie temperature | $T_c$ | 340 | 295 |

**Piezoelectric cymbals** with a similar design to the one, a are fabricated with commercial PZT ceramics (Noliac NCE51 and PiCeramics PIC 141) as piezoelectric components bonded by epoxy (EPO-TEK 353ND-T)

the metal internal diameter, $d_{Mi}$, is kept constant at a value 5 mm; the **metal thickness ($t_M$) is at 0.25** and 0.30 mm, while **the metal external diameter ($d_{Mi}$) is 17 mm**. On the other hand, **the ceramic material thickness, $t_C$ = 1 mm**, while its **diameter ($d_C$) is 29** and 30 mm. Finally, another parameter evaluated is the **cymbals cavity heights ($h_{cav}$) which is set as 0.25 and 1 mm**. The notation L, H in this manuscript denotes hcav = 0.25 and 1.00 mm,




The mechanical excitation is provided by the cars on the road. Their wheels deform the asphalt and excite the cymbals which are embedded in the pavement layers below the road layer.



A. Moure, M.A. Izquierdo Rodríguez, S. Hernández Rueda, A. Gonzalo, F. Rubio-Marcos, D. Urquiza Cuadros , A. Pérez-Lepe, J.F. Fernández Feasible integration in asphalt of piezoelectric cymbals for vibration energy harvesting. Energy Conversion and Management 112 (2016) 246–253

# หน่วยปฏิบัติการพิโซอิเล็กทริก

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ดร.หรรษกร วรรธนะสาร
อาจารย์ที่ปรึกษา

นายจักกฤษ กองพิมาย
นักวิจัย

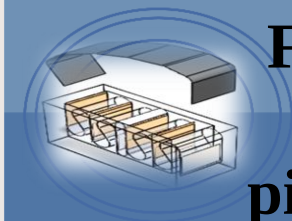
นายวัฒนา โพธิ์ตันคำ
นักวิจัย

นส.อรพรรณ เหมธุลิน
ป. โท ฟิสิกส์

นายรณชัย อินทรศรี
ป. ตรี ฟิสิกส์

นายธวัชชัย เงินนาม
ป. ตรี ฟิสิกส์

# Piezoelectric Research Laboratory Roadmap 2015-2020



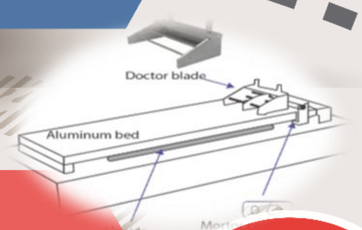
**Flexible & plastic piezoelectric**

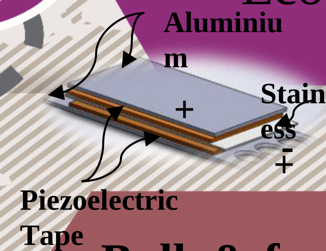
2020

2019

**Developing tape casting**

Piezoelectric device and Eco-Energy Pavement




**Tape casting**

**Piezoelectric ceramic**

thick film 100-300 µm in type of mono layer and bilayer

2018

2017

**Bulk & ferroelectric properties**

PZT-CCO, BT, PSZT

Polarization-electric field, dielectric-temperature

**Bulk & Piezoelectric properties**

PZT-PFN, PFN-PT-Zn,

Dielectric, poling high voltage and d33 coefficient

2016

2015

**Bulk piezoelectric**

Synthesized piezoelectric ceramic PMN-PZT

PERL PIEZOELECTRIC Research Laboratory

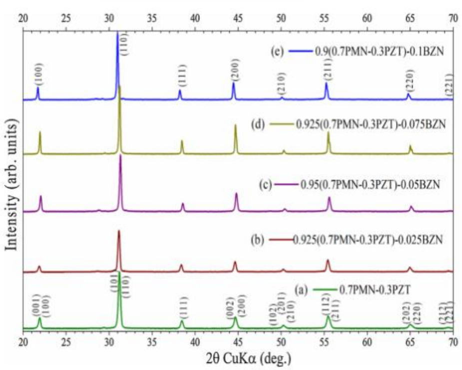
| Bulk | Piezoelectric properties | Ferroelectric properties | Tape casting | Piezoelectric device | Flexible & plastic piezoelectric |
|---|---|---|---|---|---|

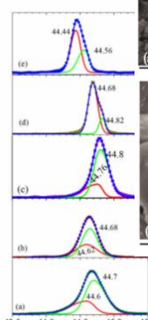
# Synthesis

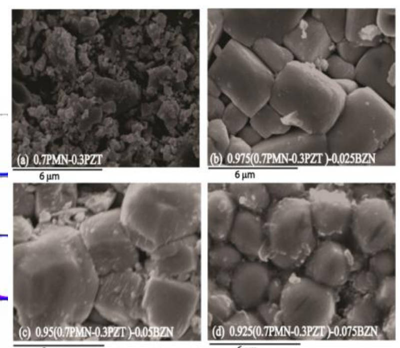
**Materials** *PZT type* : PMNZT, PSZT

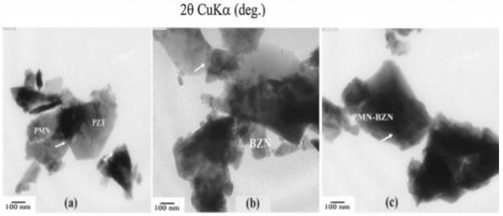
*free–lead type* : BZN, KNNL, BT, BSCZT

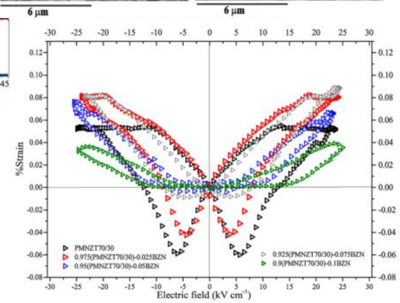
**Method** Solid State Reaction

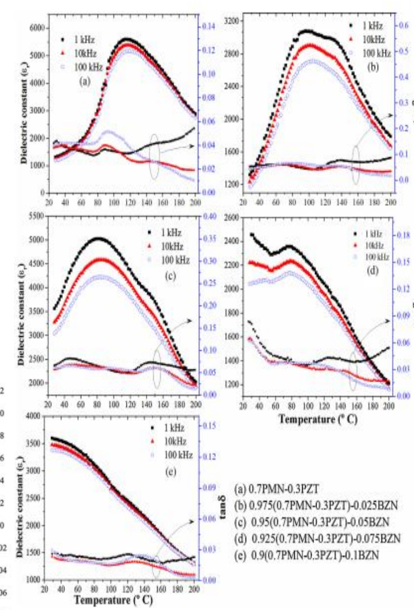


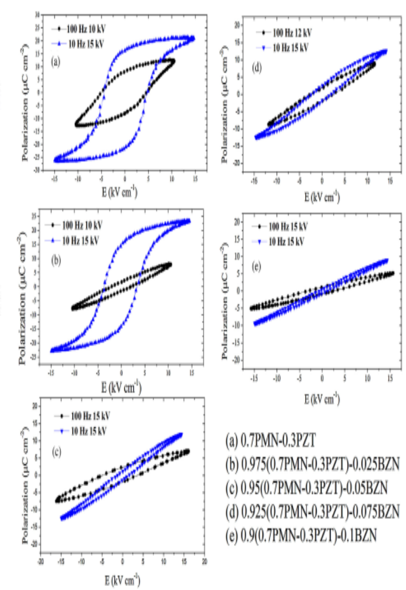





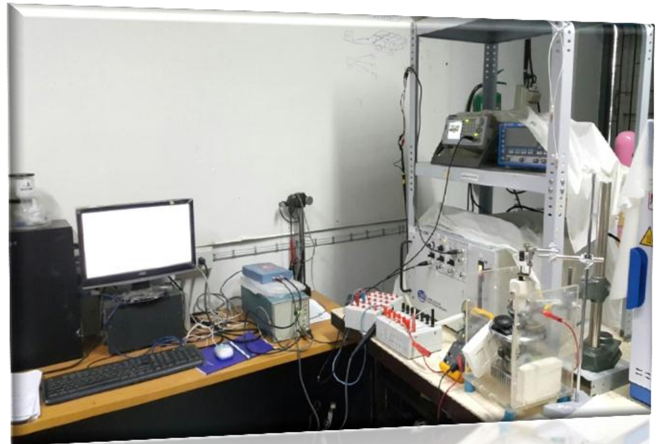



# Research Instrumentation


Dielectric Constant testing

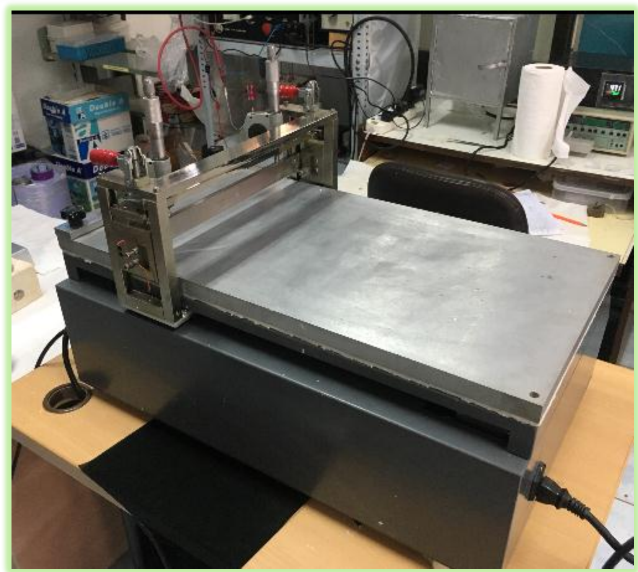


Hysteresis Electric Loop


Piezoelectric Coefficient Meter

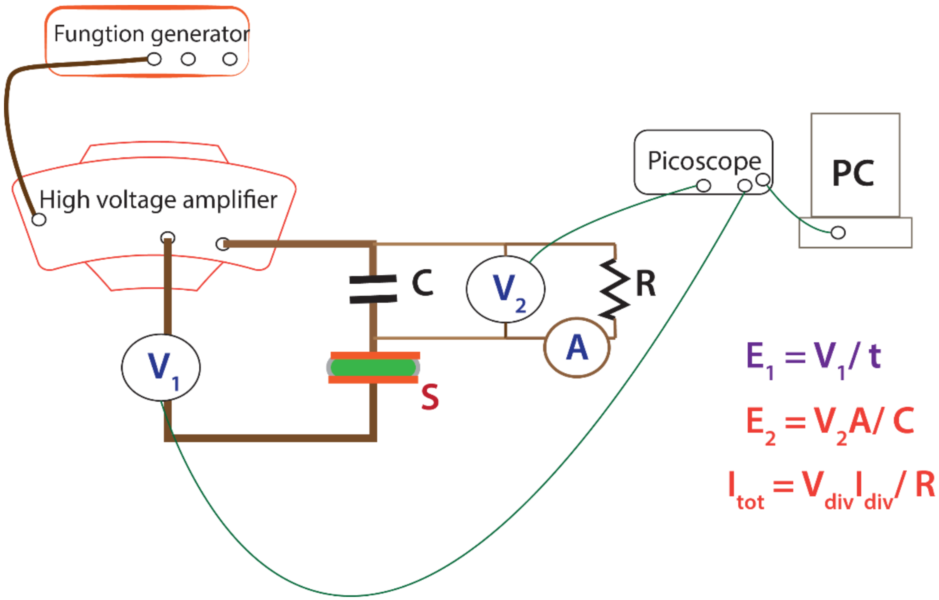
Piezoelectric Harvesting Machine

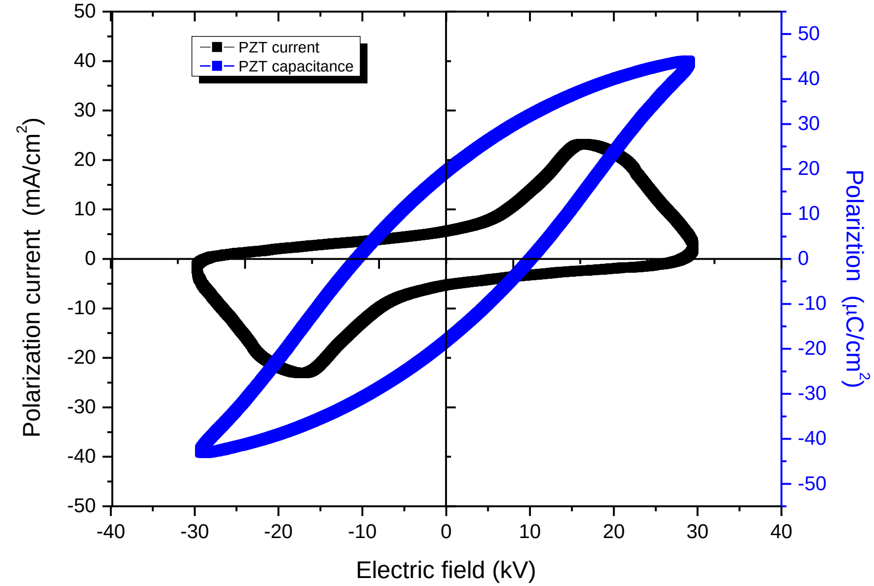

Vacuum mixer



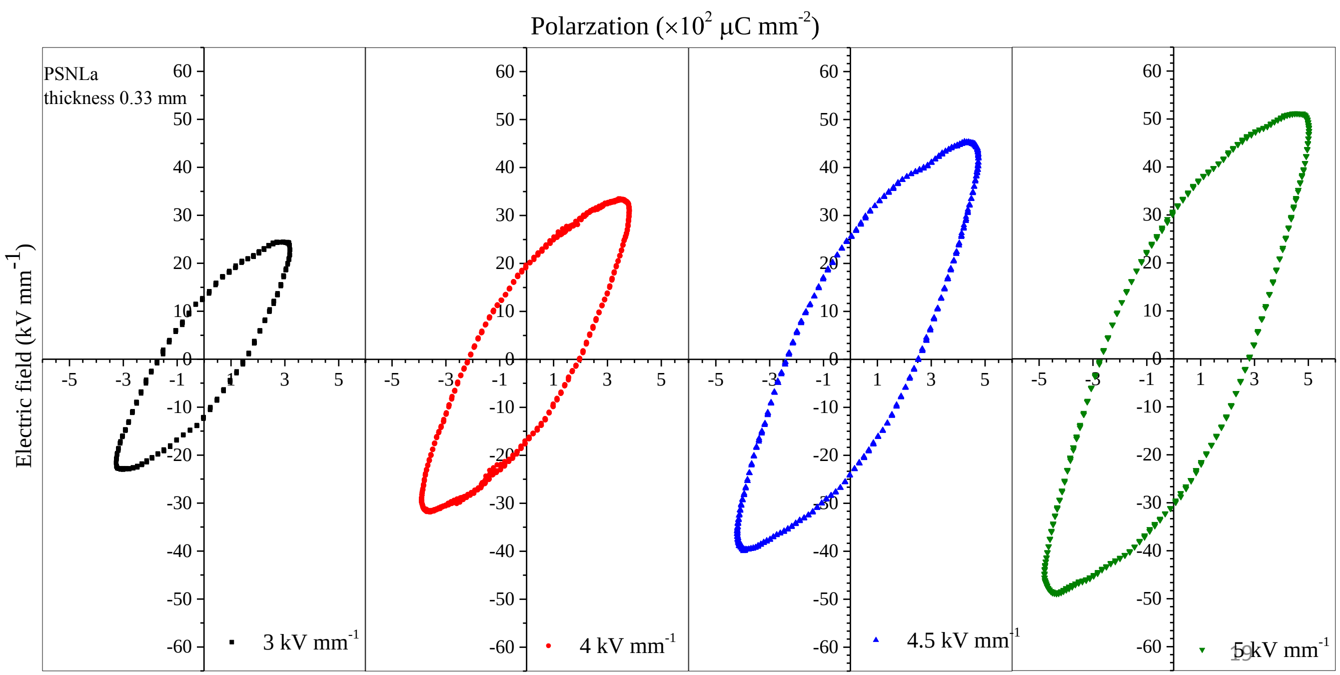
Tape casting

Viscosity meter



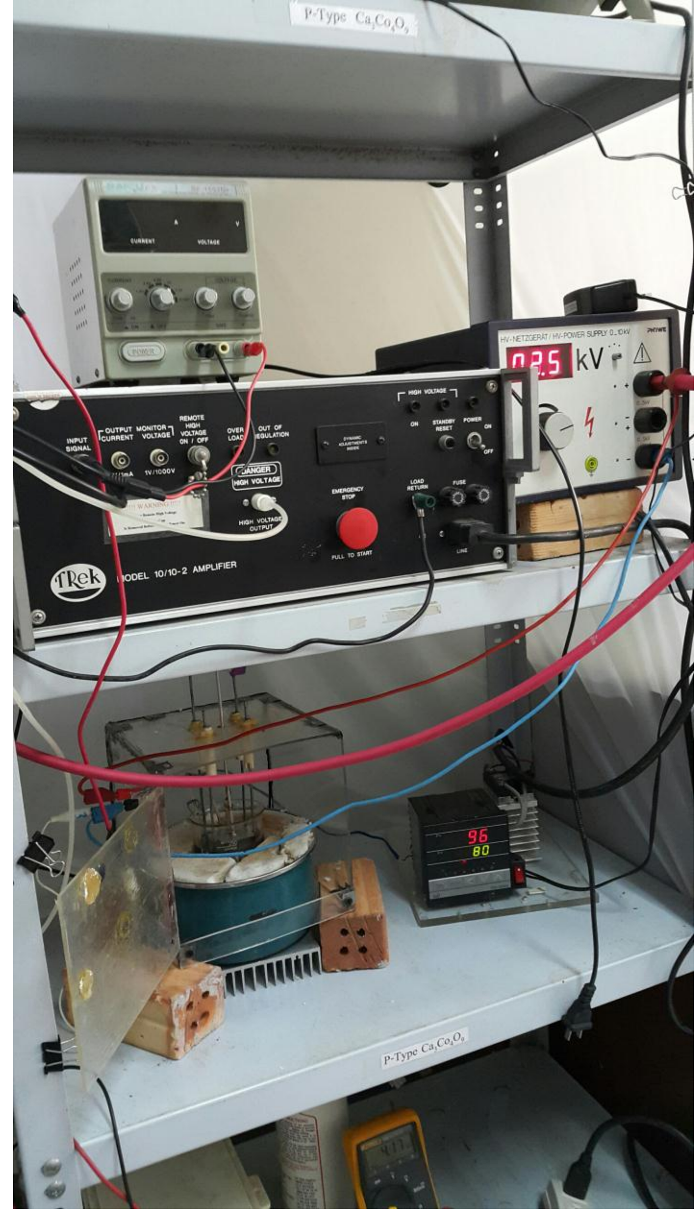

# P-E curve & I-E curve



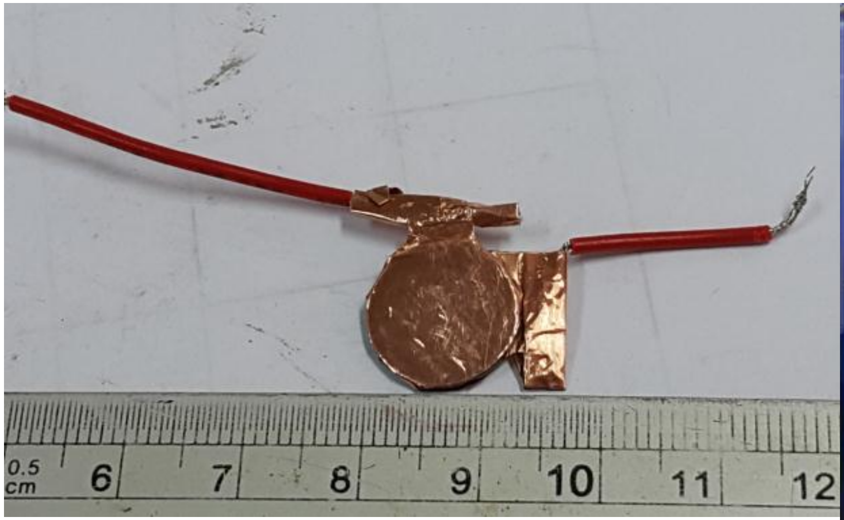
แผ่นเทปจากการอบ 200 ° C

แผ่นเทปจากการเผาผนึก 1175 ° C

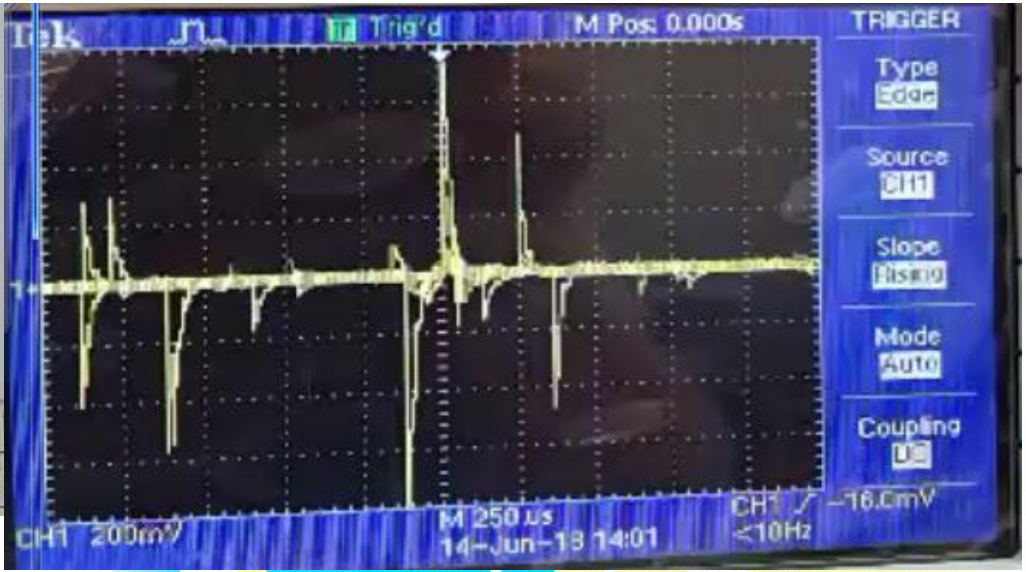
ความหนา 0.4-0.8 mm



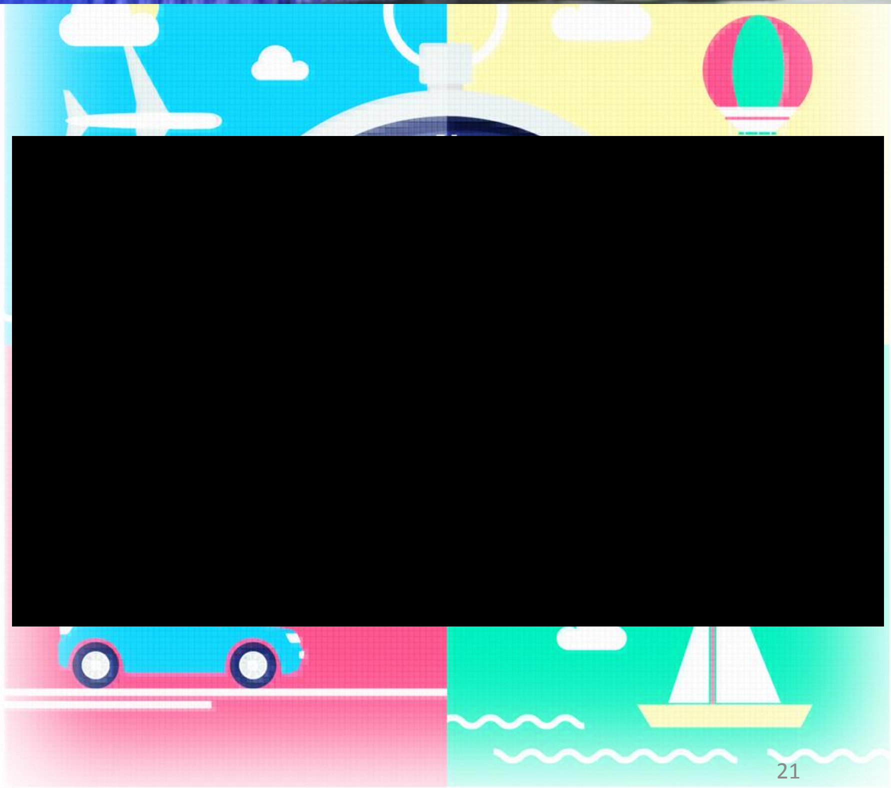

การเหนี่ยวนำขั้วไฟฟ้า 1.5 – 4 kV $mm^{-1}$



0.5
cm
6
7
8
9
10
11
12



Tek
Trig'd
M Pos: 0.000s
TRIGGER
Type
Edge
Source
CH1
Slope
Rising
Mode
Auto
Coupling
DC
CH1 200mV
M 250us
14-Jun-18 14:01
CH1 / -16.0mV
<10Hz



# Publication 2017-2018

1. Hassakorn Wattanasarn*, Wattana Photankham, Peeraphat Pattumma & Rattikorn Yimnirun, (2017) Phase transition and dielectric properties of 0.9Pb(Fe1/2 Nb1/2)O3–0.1PbTiO3 ceramics doped with ZnO Pertanika Journal of Science & Technology, Vol. 25 (2) (2017) 527–536. Q3
2. Tosawat Seetawan*, Wattana Photankham, Hassakorn Wattanasarn, Sunti Phewphong, (2017) Influence of nano carbon black added BaTiO3 on physical and dielectric properties. Materials Today: Proceedings, Vol. 4(5): pp. 6472-6477.
3. Hassakorn Wattanasarn*, Wattana Photankham, Jukrit Kongpimai, Chanchana Thanachayanont and Rattikorn Yimnirun. Effect of ZnO addition on ferroelectric properties of 0.94Pb(Fe1/2 Nb1/2)O3-0.06PbTiO3 and 0.9Pb(Fe1/2 Nb1/2)O3-0.1PbTiO3 ceramics. Integrated Ferroelectrics, 187 (1), (2018) 33-44 https://doi.org/10.1080/10584587.2018.1445393, Impact Factor = 0.457, Q3
4. Wattana Photankham, Jukrit Kongpimai, Sunti Phewphong, Hassakorn Wattanasarn*, Suvich Samapisut, and Achara. Namthaisong. Effect of PFN addition on microstructure and piezoelectric properties of PZT58/42 ceramics. Integrated Ferroelectrics, Vol. 187 (1), (2018) . 80-88. https://doi.org/10.1080/10584587.2018.1445685, Impact Factor = 0.457, Q3
5. Jukrit Kongpimai, Wattana Photankham, Achara. Namthaisong, Sunti Phewphong, Hassakorn Wattanasarn*. Dielectric and ferroelectric properties of Pb(Zr0.53Ti0.47)O3 ceramics modified with Sr. Integrated Ferroelectrics, 187(1) (2018), 14-19. https://doi.org/10.1080/10584587.2018.1445357. Impact Factor = 0.457, Q3
6. Sunti Phewphong, Wattana Photankham, Jukrit Kongpimai, Chanchana Thanachayanont and Rattikorn Yimnirun. Dielectric and ferroelectric properties of $Pb(Fe_{1/2} Nb_{1/2})O_3$ modification on $Pb(Zr_{0.52}Ti_{0.48})O_3$ ceramics. Integrated Ferroelectrics, 187:(1) (2018), 89-99. https://doi.org/10.1080/10584587.2018.1445687, Impact Factor = 0.457, Q3.


Thank you for your attention