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Hafnium Zirconium Oxide Thin Films for CMOS Compatible Pyroelectric Infrared Sensors

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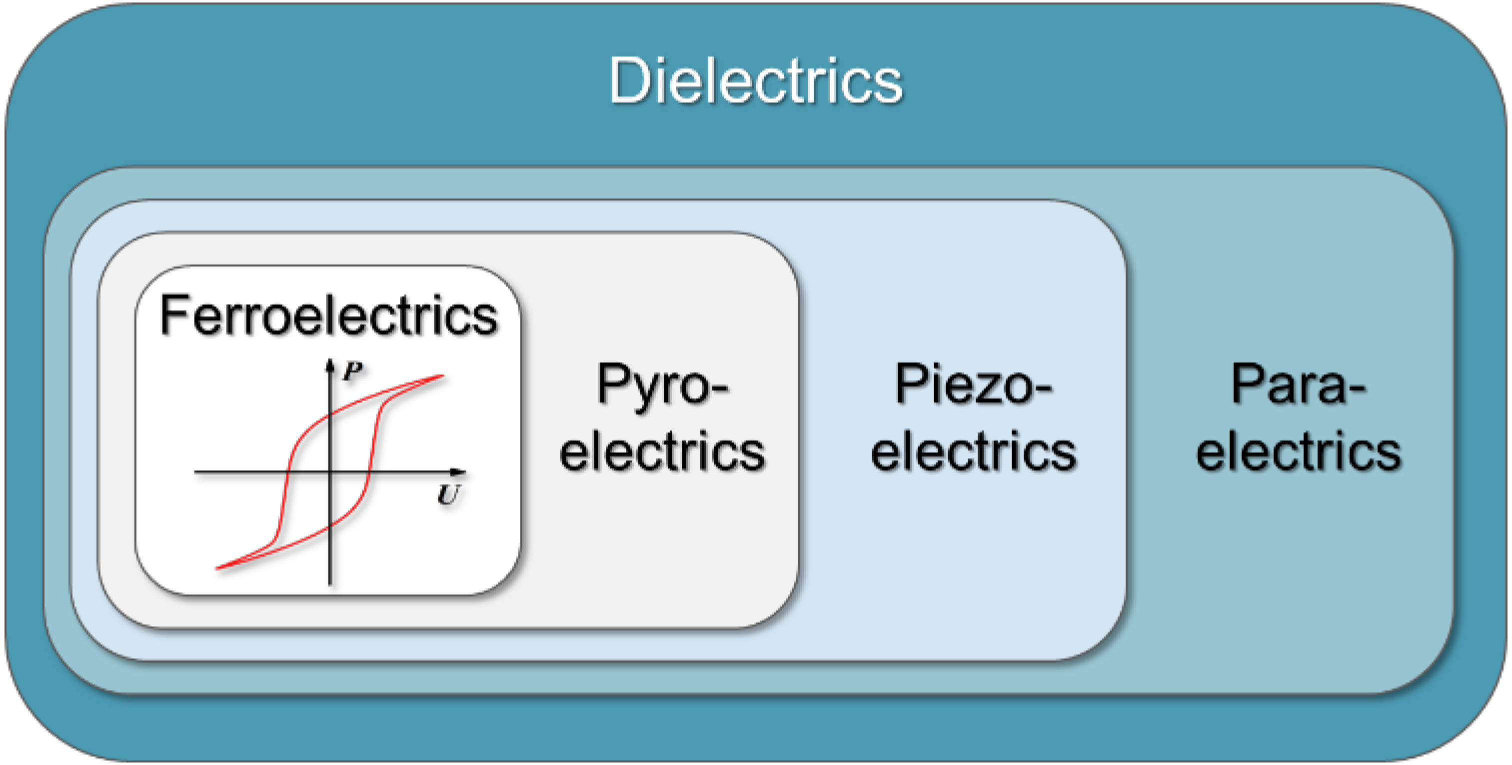
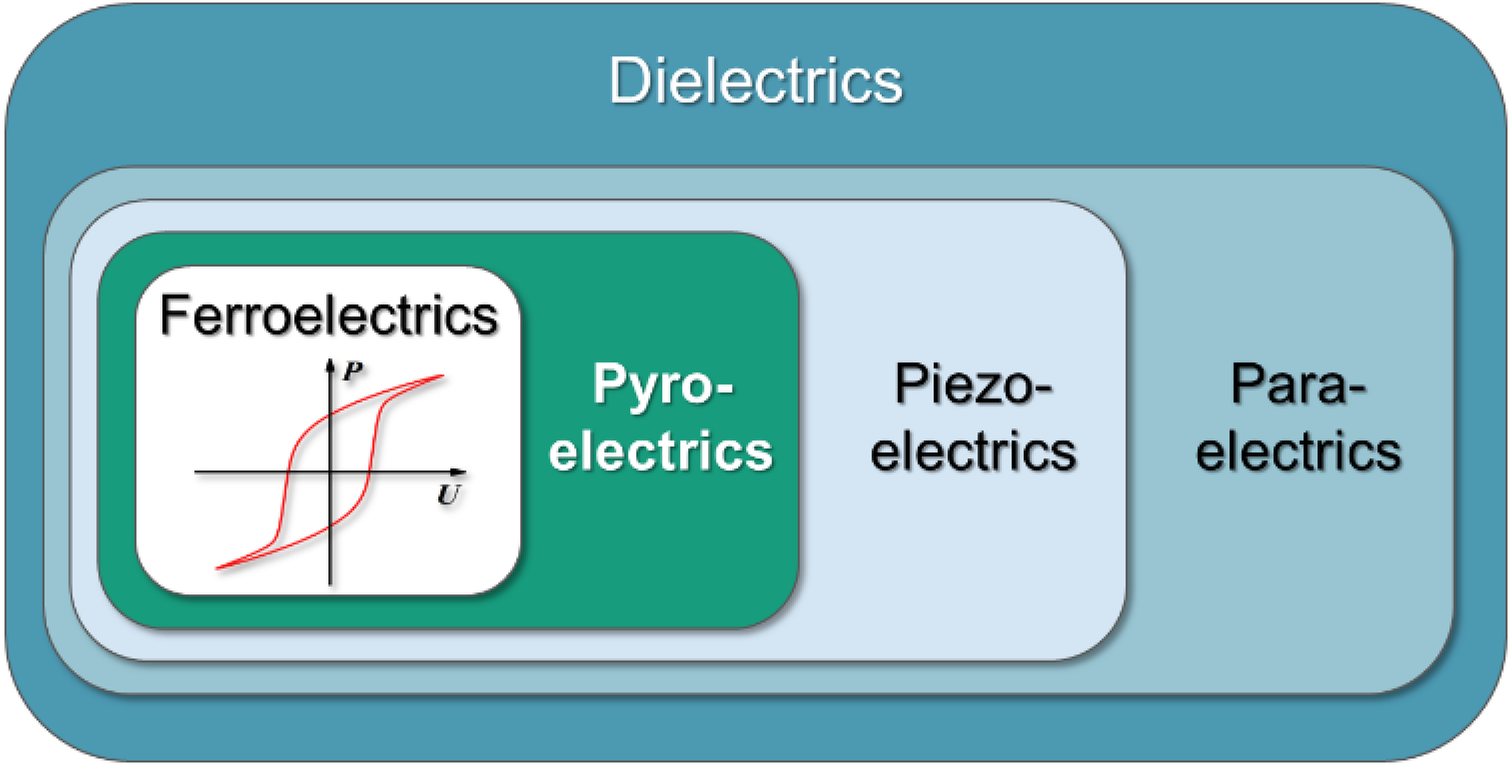
Pyroelectricity
Overview



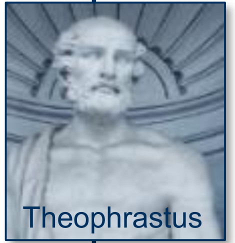
Pyroelectricity

Overview



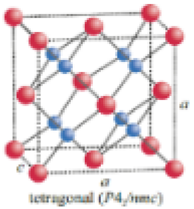
Doped hafnium oxide: A brief history

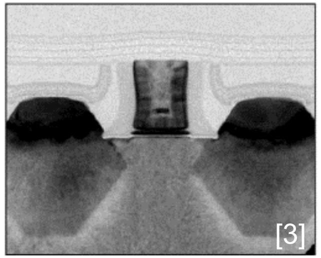
Discovery of pyroelectricity



Discovery of ferroelectricity [1]

Unusual phases, polymorphism in HfO_2 [2]

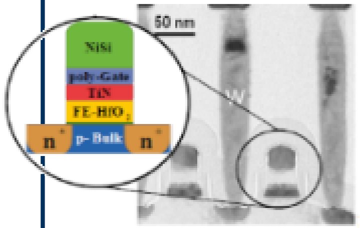




HfO_2 and ZrO_2-based field effect transistors and random access memory (DRAM)

Discovery of ferroelectricity in HfO_2

HfO_2 based me-mory ("FeFET") [4]



314 BC | 1921 | 1989 | early 2000s | 2007 | 2011

[1] J. Valasek Physical Review 17.4 (1921)
[2] E. Kisi et al. J. Am. Ceram. Soc. 72 (1989)
[3] K Mistry et al., IEDM 2007
[4] J. Müller et al., IEDM 2013

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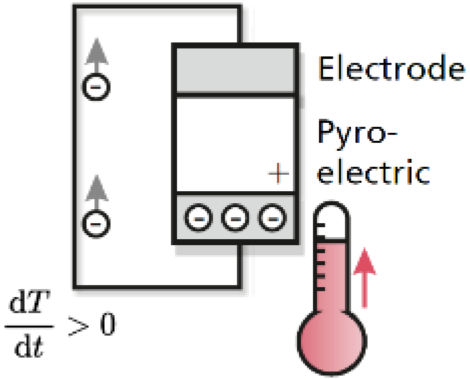
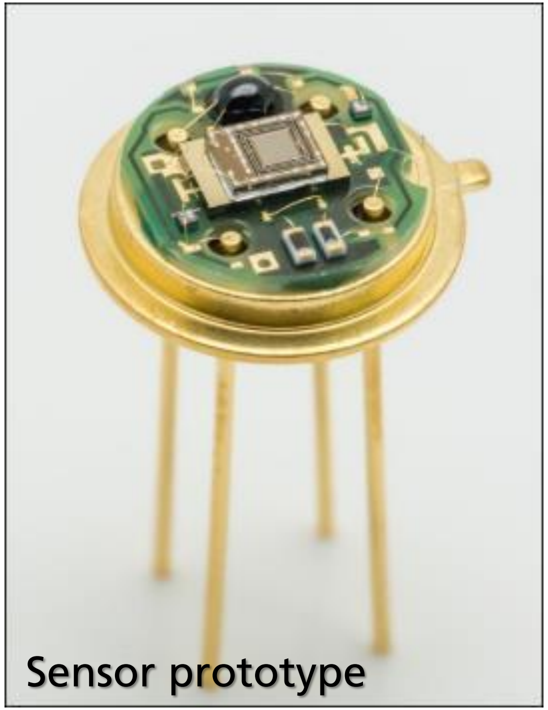
Pyroelectric Infrared Sensors

Working principle

- The pyroelectric effect corresponds to a polarization change upon temperature variation

$$p_i = \underbrace{\frac{\partial P_i}{\partial T}}_{\text{intrinsic}} + \underbrace{E_j \frac{\partial \varepsilon_{ij}}{\partial T}}_{\text{field-induced}}$$



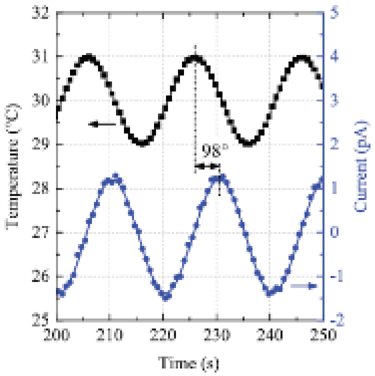


Sensor prototype

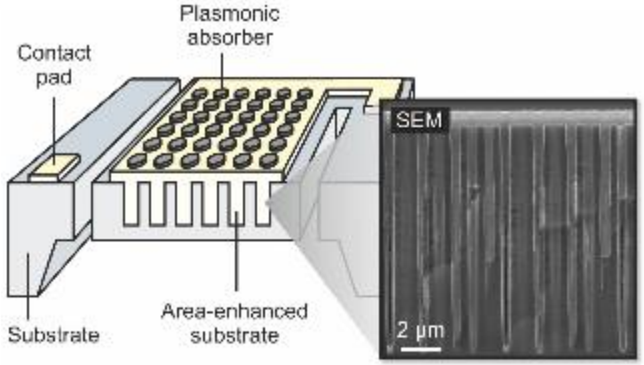
- The effect can be used for infrared detection
- The generated current is proportional to the rate of temperature change

Infrared Sensor development steps

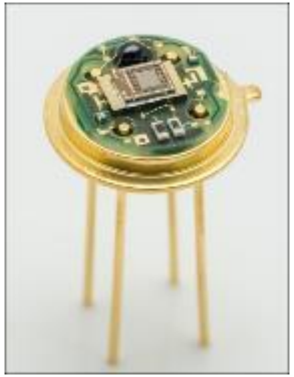
Pyroelectric effect in doped HfO_2 → Area-enhanced pyro-HfO_2 → MEMS integration → Infrared Sensor element → CO_2 Sensor



Mart et al., Appl. Phys. Lett. 112, 052905 (2018)



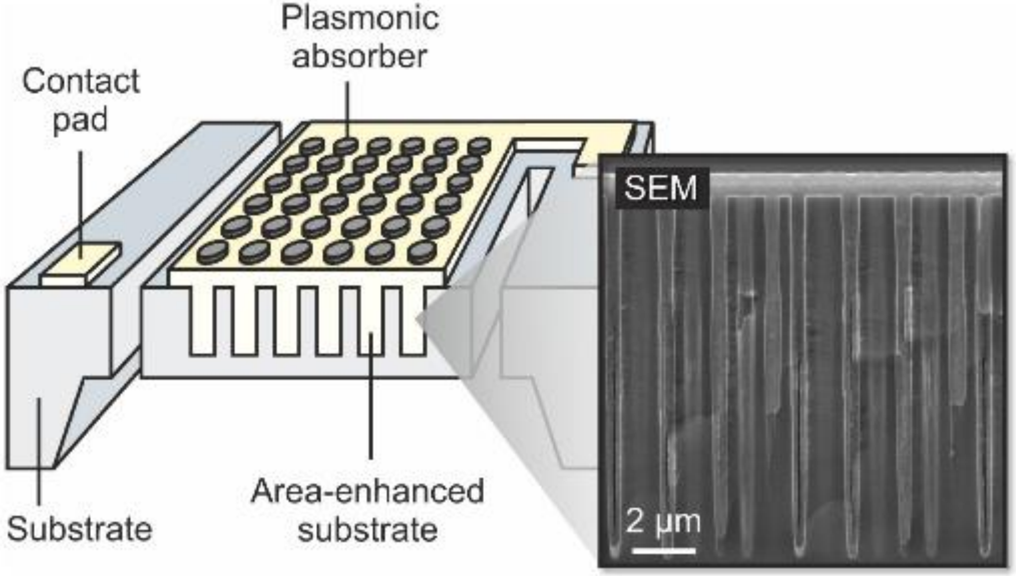
Mart et al., IFCS ISAF 2019



Kindly provided by Infratec GmbH

Pyroelectric sensor technology
Manufacturing process

- Area-enhanced substrate with 3D structures is used to enhance the pyroelectric response by approx. 20x
- MEMS post-processing forms a thin membrane with reduced heat capacity for fast response
- A further MEMS step isolates the sensor area thermally from the body via “fingers”
- A plasmonic absorber array is formed in the metallization layer
- 300mm technology with i-Line lithography



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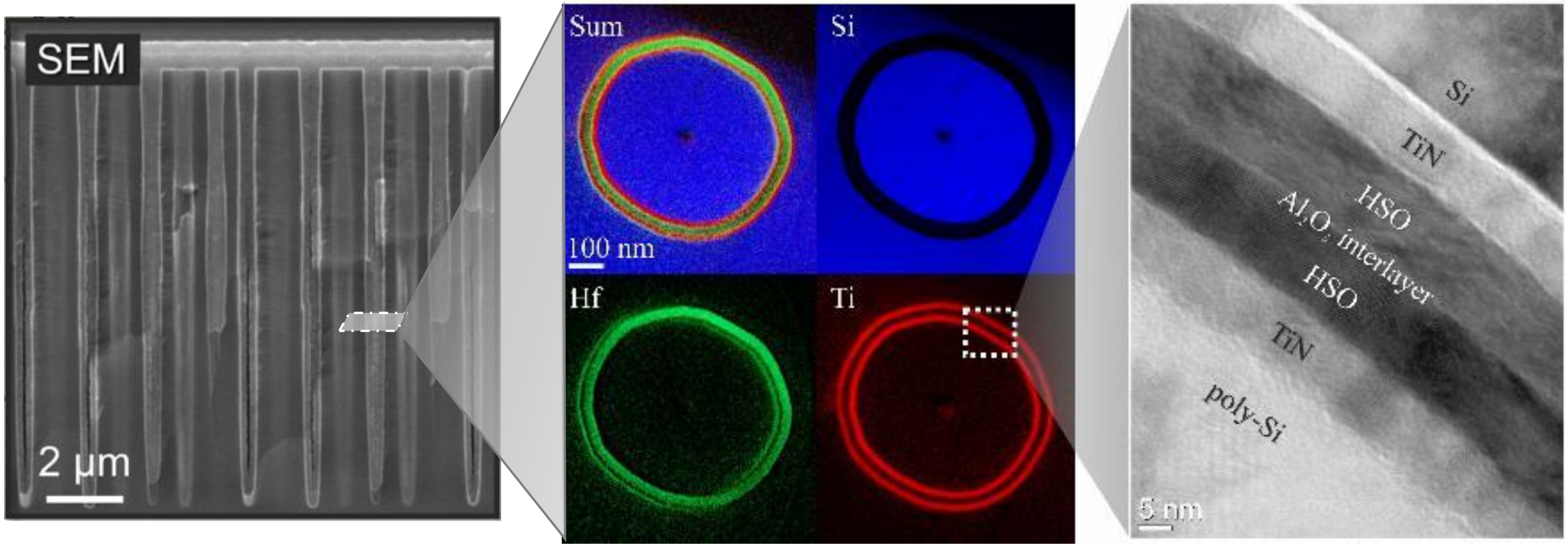
3D integration of doped HfO_2 thin films

- Pyroelectric material: 20 nm thick, 4 mol% Si-doped HfO_2 with Al_2O_3 interlayer ("nano-laminate")
- The conformal coating of the 3D structures is confirmed



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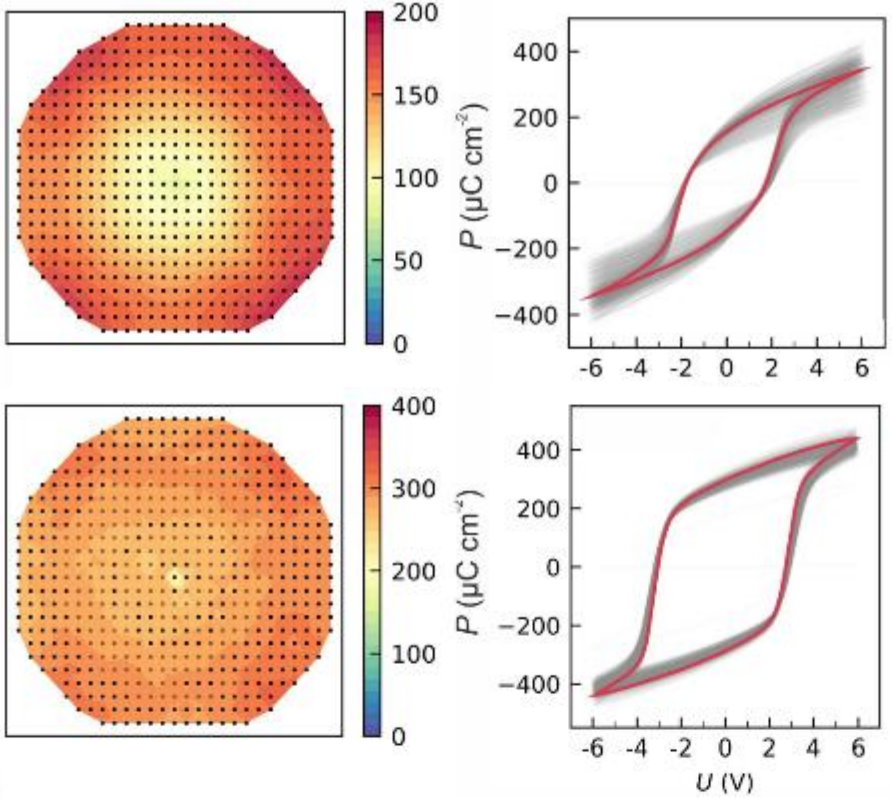
Electrical characterization

Ferroelectric properties

- Ferroelectric polarization of doped HfO_2 on area-enhanced 300mm substrate with 532 dies.
  - $HfZrO_2$ exhibits a improved uniformity and larger remanent polarization, up to 331 µC cm^{-2}
  - Specific area of 11.3 to 15.0 compared to planar results by 3D integration
- Low defect density, >99% functional devices

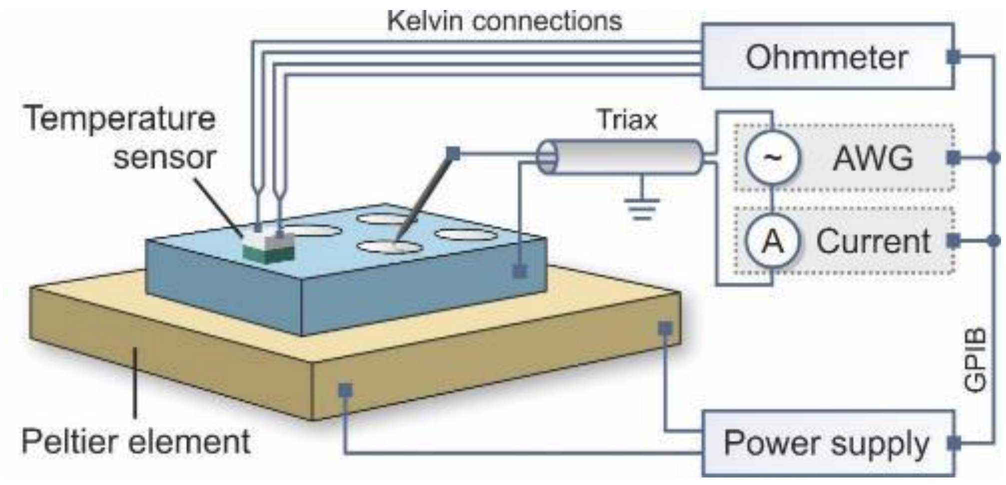
Si-doped HfO_2:

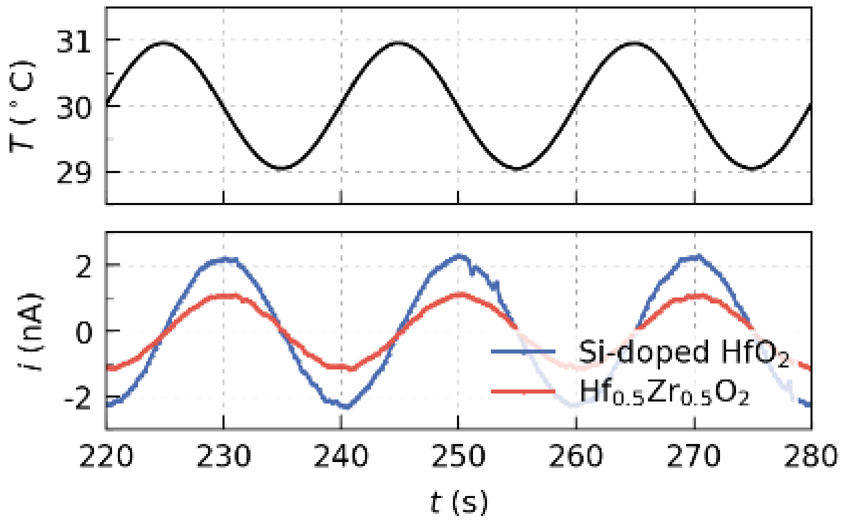
$Hf_{0.5}Zr_{0.5}O_2$:



Pyroelectric characterization

- Pyroelectric measurement is performed by sinusoidal temperature variation ("Sharp-Garn method")
- Although the remanent polarization is smaller, Si-doped HfO_2 realizes larger pyroelectric current amplitudes

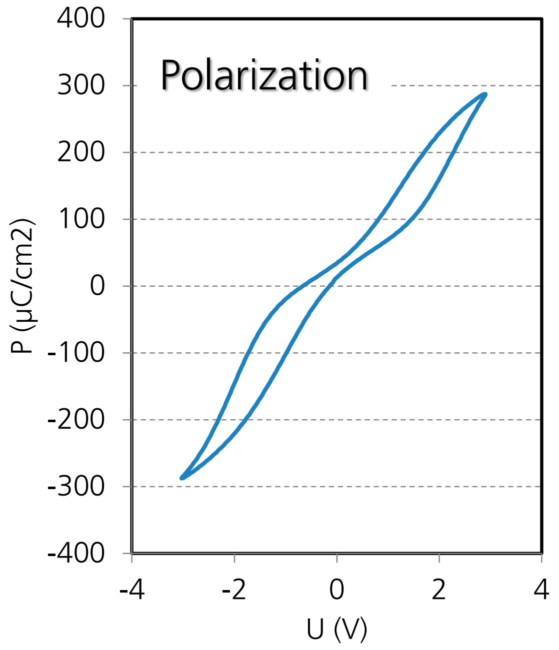


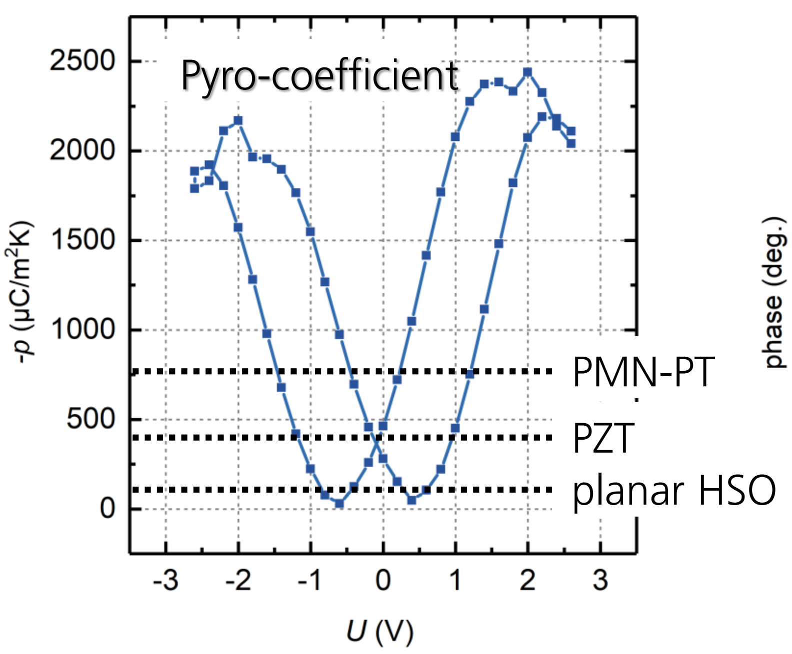


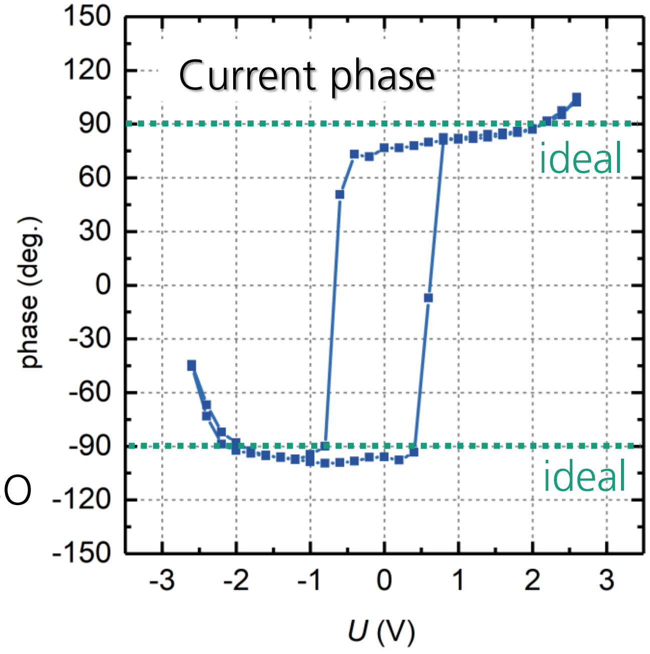
	Si-doped HfO_2	$Hf_{0.5}Zr_{0.5}O_2$
Virtual pyroelectric coeffiient	-1039 $\mu Cm^{-2}K^{-1}$	-475 $\mu Cm^{-2}K^{-1}$
Dielectric permittivity	36.9	37.8
Aging coefficient	-5.7 %/dec.	-3.6 %/dec.

Combining 3D integration and antiferroelectricity

- By tuning the Si doping content higher, antiferroelectric behavior is stabilized
- Very large pyroelectric coefficients by combining area enhancement and AFE enhancement
  - p = -2400 µC/m²K

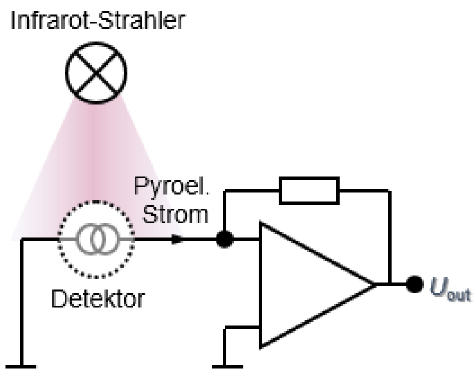


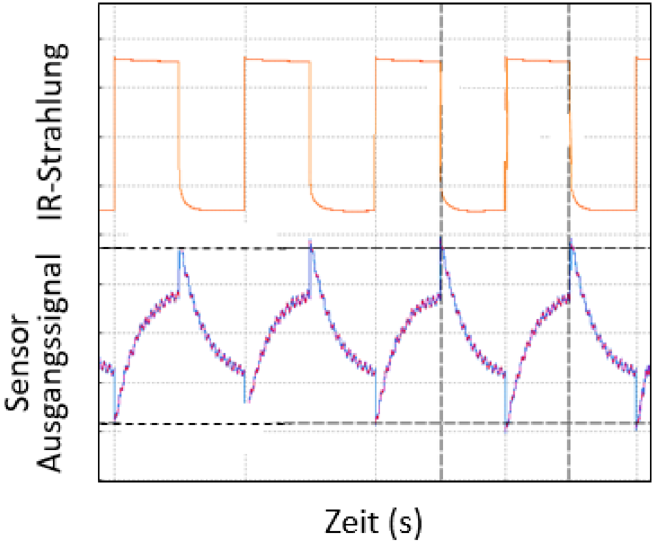




IR Sensor Test

- The sensor current is amplified and converted to a voltage
- The manufactured sensor element produces a signal which is proportional to the amplitude of the incident infrared light





Thank you for listening!

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EFRE

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