



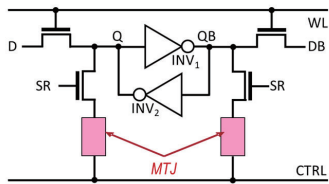
## Integrated Electronics for Ultralow-Power Edge/Wearable Computing and Internet-of-Humans

■ CMOS Integrated circuits ■ Beyond-CMOS devices/circuits ■ Micro thermoelectric generators

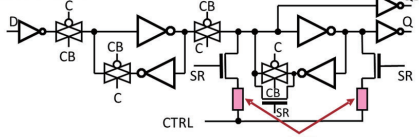
FIRST, Imaging Science and Engineering Research Center

### Low-standby-power CMOS logic technology using nonvolatile retention

#### ■ NV-SRAM

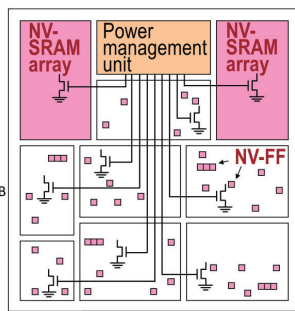


#### ■ NV-DFF

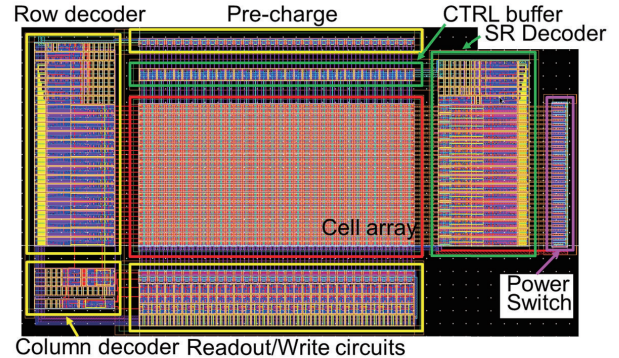


- Nonvolatile bistable retention/memory circuits based on NVM/CMOS hybrid technology
- Energy-efficient nonvolatile-power-gating architectures using nonvolatile retention

#### ■ Nonvolatile power gating system



#### ■ NV-SRAM Macro

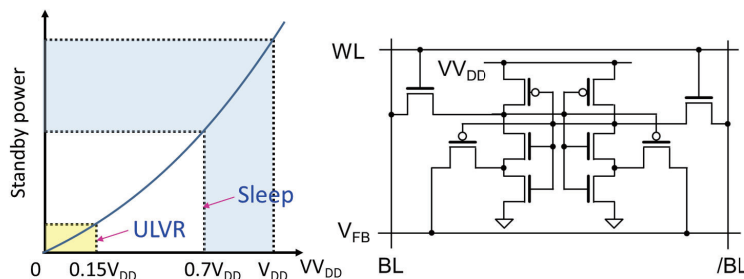


Column decoder Readout/Write circuits

- NV-SRAM → Highly effective at reducing standby power for caches
- Applications: Microprocessors/Microcontroller and Processing-in-memory units (e.g. neural accelerator)

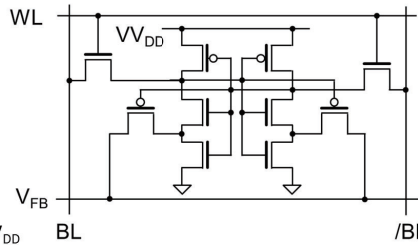
### Highly energy-efficient power-gating architecture based on ultralow-voltage retention

#### ■ Ultralow-voltage retention (ULVR)

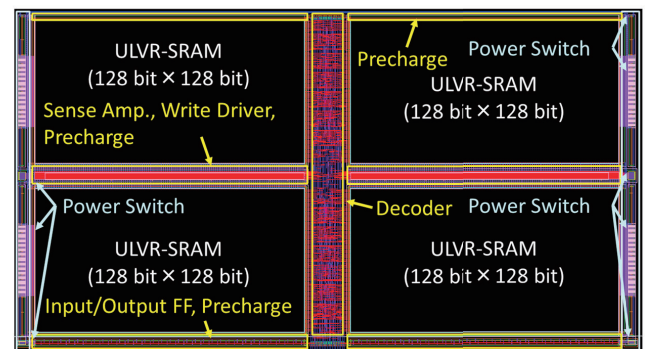


- Conv. 6T-SARM: Sleep mode ( $0.7V_{DD}$ ) → Insufficient static power reduction
- ULVR-SRAM: ULVR at  $0.15V_{DD}$  → Highly efficient static power reduction
  - Normal inverter (NI) mode: High-performance operation at  $V_{DD} = V_{DD}$
  - Schmitt trigger (ST) mode: ULVR at  $V_{DD} = 0.15V_{DD}$

#### ■ ULVR-SRAM cell



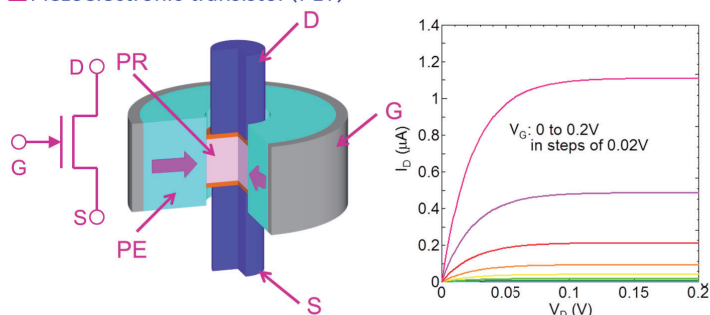
#### ■ 8kB ULVR-SRAM Macro



- ULVR-SRAM → Completely CMOS-compatible technology for highly efficient static power reduction
- Applications: Microprocessors, SoCs, and Processing-in-memory units (e.g. neural accelerator)

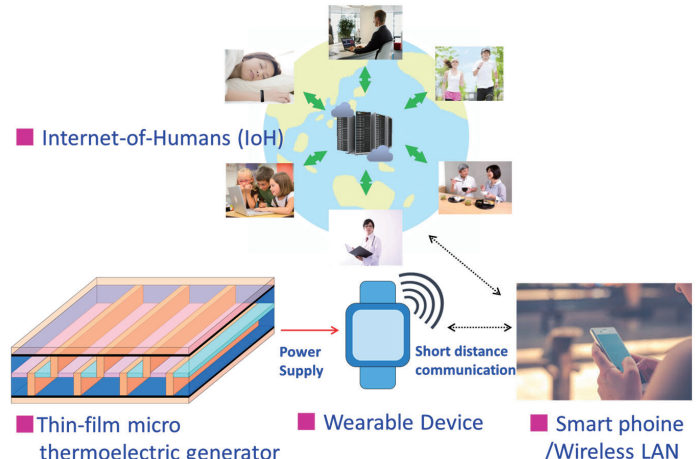
### Beyond-CMOS devices and circuits for ultralow-voltage high-speed logic systems

#### ■ Piezoelectronic transistor (PET)



- Piezoresistive channel + Piezoelectric gate → Switching based on pressure-induced metal-insulator transition
- High current drivability at ultralow voltages
- Low leakage
- CMOS compatible circuits

### Micro thermoelectric generators using body heat for wearable devices



■ Thin-film micro thermoelectric generator

■ Wearable Device

■ Smart phone /Wireless LAN