Programmable black phosphorus image sensor for broadband optoelectronic edge computing

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Introduction

- The conductivity of black phosphorus (BP) changes dramatically depending on the charge doping level, and so does the responsivity at wide wavelength ranges from visible to Mid-IR light [1].
- The doping level of the BP channel can be manipulated by concentration of local charges, which can be stored in non-volatile manner by engineering the stack of dielectric layers (AHA) [2].
- As BP-transistors are connected in an array, it can perform basic convolutional neural network tasks in a vision sensor, enabling edge computing [3].

Black Phosphorus Phototransistor Design

BP Phototransistor structure and the Optical image

- \( \text{Al}_{2} \text{O}_{3}/\text{HfO}_{2}/\text{Al}_{2} \text{O}_{3} \) stack of dielectric layers traps charges in the \( \text{HfO}_{2} \).
- ITO for transparent top gate
- BP (11 nm) as a channel material with 200 on-off ratio
- ~8% inter-device variation

Device retention time, repeatability and durability

- Electrically programmed states: retention time (30%) – 1 year.
- Repeatability: conductance states over 200 programming cycles with long retention time >1000s

Electrical/Optical Programming and Readout

- 18 V top gate pulse makes the BP channel least conductive (erased)
- Different top gate pulses (10 – 18 V) set the channel conductivity (programmed)
- Each state shows linear I-V characteristics.
- Optically programmed states: Fine control of the states with 36 states.
- Each state separated well in conductivity, and stayed stable > 1000 s.
- Programmable responsivity over broad IR spectra
- Linear dependence of optical power and photocurrents.

Optoelectronic Edge Detection

- Different images encoded in different NIR wavelength regime.
- Optoelectronic convolutional Kernel calculation results in clear edge detection.

Hand-written digit classification

- Input can also be encoded electrically.
- 36 steps, or more than 5 bits of conductivity states enable the computation with more complex kernel matrix.
- MNIST hand-written digits are classified for randomly picked ‘0’ and ‘1’ with 92% accuracy. [4]

References