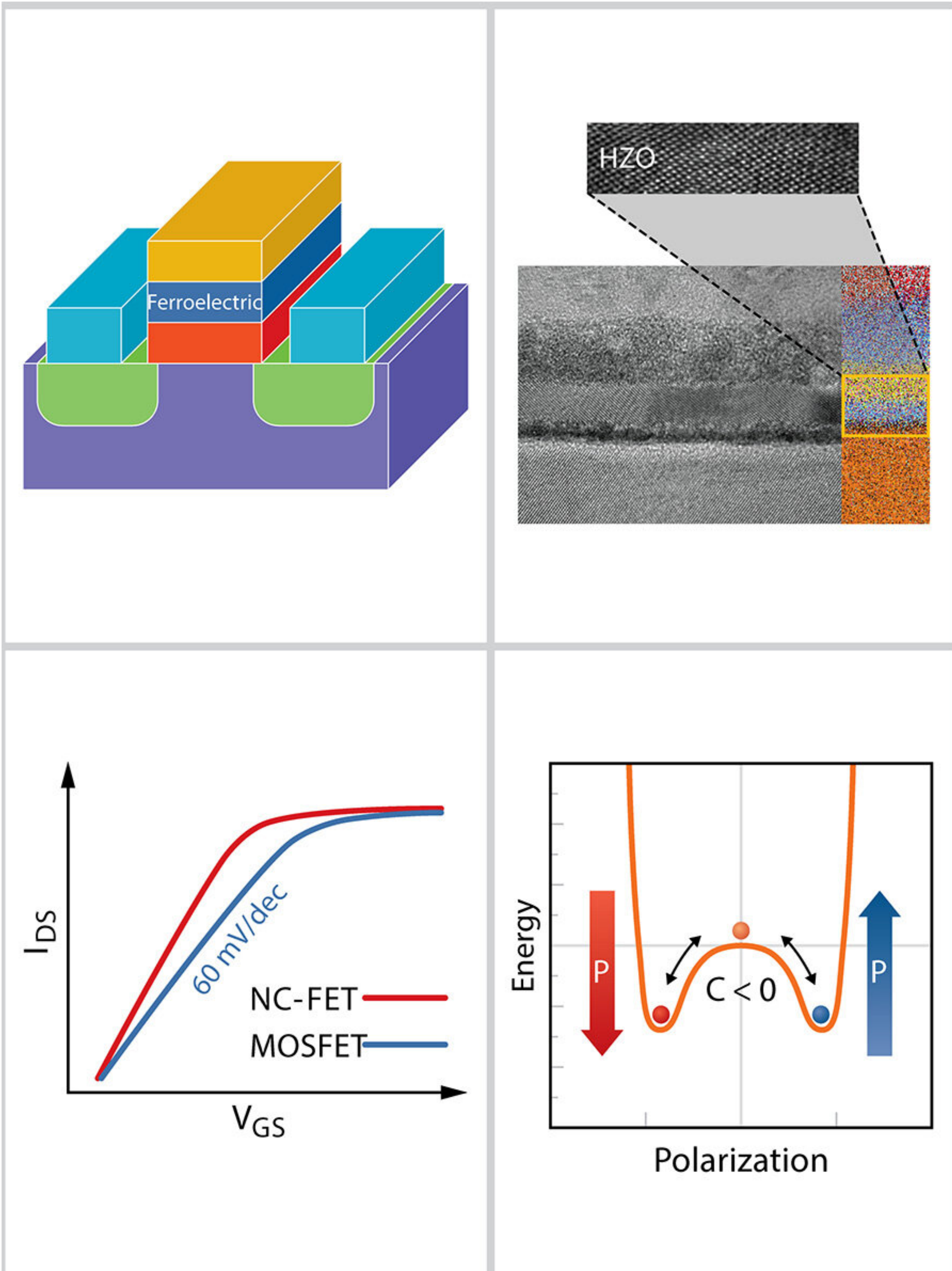
Looking back and forward: A decadelong quest for a transformative transistor

March 13 2019


Ferroelectric
HZO
I_DS
60 mV/dec
NC-FET
MOSFET
V_GS
Energy
P
C < 0
P
Polarization

This is a schematic image of a NC-FET where a CMOS-compatible ferroelectric HZO layer is part of the gate stack to realize negative capacitance in the gate stack and sub-60 mV/dec transistor operation. Credit: Peide D. Ye

Smartphones contain billions of tiny switches called transistors that allow us to take care of myriad tasks beyond making calls—sending texts, navigating neighborhoods, snapping selfies and Googling names. These switches involve an electrically conducting channel whose conductivity can be changed by a gate terminal, which is separated from the channel by a dielectric film that's a mere 5 to 6 atoms thick.

Transistors have been miniaturized for the past 50 years based on Moore's law, an observation that the number of transistors on a chip can double roughly every 18 months while the cost is cut in half. But we've now reached the point where transistors can't continue to be scaled any further.

In the journal *Applied Physics Letters*, researchers review negative capacitance field-effect transistors (NC-FETs), a new device concept that suggests traditional transistors can be made much more efficient by simply adding a thin layer of ferroelectric material. If it works, the same chip could compute far more, yet require less frequent charging of its battery.

The physics of the technology are being assessed throughout the world and, in their article, the researchers summarize state-of-the-art work with NC FETs and the need for self-consistent and coherent interpretation of a variety of experiments being reported in the literature.

"NC FETs were originally proposed by my colleague professor Supriyo Datta and his graduate student Sayeef Salahuddin, who is now a professor at the University of California, Berkeley," said Muhammad Ashraful Alam, a professor of electrical and computer engineering at Purdue University.

From the very beginning, Alam found the concept of NC-FETs intriguing—not only because it addresses a pressing problem of finding a new electronic switch for the semiconductor industry, but also because it serves as a conceptual framework for a broad class of phase-transition devices collectively termed "Landau switches."

"More recently, when my colleague and co-author professor Peide Ye started experimentally demonstrating these transistors, it was an opportunity to work with him to explore deeply intriguing features of this device technology," Alam said. "Our article summarizes our 'theorist-experimentalist' perspective regarding the topic."

Although hundreds of papers have been published on the topic, according to the researchers, the validity of quasi-static NC and the frequency-reliability limits of NC-FET are still being hotly debated.

If conclusively demonstrated and integrated into modern ICs, the impact of the NC-FET transistors will be transformative. "Given the potential, there is a need for systematic analysis of the device concept," said Ye. "We found that the data from various groups has a wide scatter and researchers are using very different techniques to characterize their devices. This requires an integrated and comprehensive analysis of the existing data set."

The researchers hope their work will bring the community together to suggest ways of making coordinated progress toward realizing this promising technology.

More information: Muhammad A. Alam et al, A critical review of recent progress on negative capacitance field-effect transistors, *Applied Physics Letters* (2019). DOI: 10.1063/1.5092684

Provided by American Institute of Physics