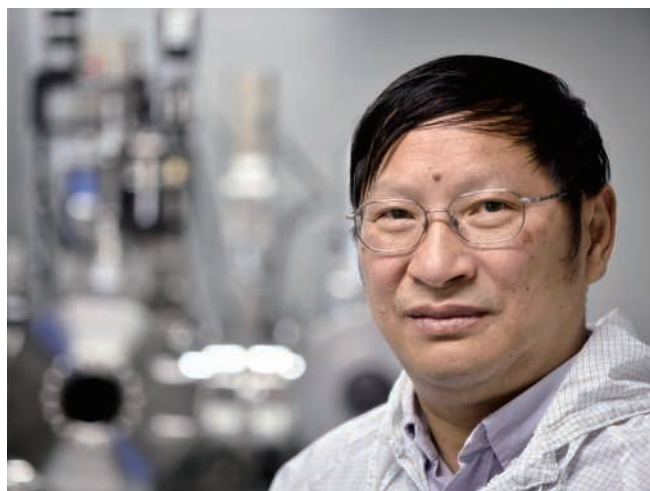


Pioneering carbon-based nanoelectronics

Researchers at **PEKING UNIVERSITY** have developed technology to build smaller and more efficient integrated circuits with carbon nanotubes, opening the door to a future beyond silicon chips.



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It is globally recognized that Moore's law, the golden rule that has allowed the semiconductor industry to cram ever more silicon transistors on to chips, is running out of steam. A technique based on carbon nanotubes (CNTs) developed at Peking University (PKU) has given Moore's law a new lease of life, making chips five times faster than silicon-based ones, according to Peng Lian-mao, the PKU professor who led the study.

It is predicted that silicon complementary metal-oxide semiconductor (CMOS), the most popular mode for integrated circuits, will reach

their limit by 2020, scientists around the world have been searching for new materials for replacement. Carbon nanomaterials like graphene and CNTs are promising, given their potential to make transistors even smaller, faster and more energy-efficient. Their better flexibility and biocompatibility compared with silicon also offer potential for wearable electronics and medical devices.

While the carbon-based technology is rapidly developing, it is still much less advanced than silicon. After more than 50 years of development, billions of

transistors can be packed on to a single chip.

Peng's team has been exploring carbon-based nanoelectronics since 2001. With steady funding from national and local governments, the team has achieved breakthroughs by developing a whole set of techniques for fabricating CNT CMOS and integrated circuits, as well as optoelectronic devices. The core of their technology is a doping-free method that achieves polarity control of transistors by selectively injecting electrons or holes into CNTs with suitable contact materials. "It is hard for CNT CMOS to outperform silicon using doping," said Peng. The doping-free technique can greatly simplify the fabrication steps, reduce the damage to carbon nanomaterials, and improve performance of devices, presenting the potential to improve on silicon-based technology.

More recently, Peng's team demonstrated CNT transistors with a gate length of only five nanometres (nm), which operate ten times faster and at much lower supply voltage than standard silicon CMOS devices. It approaches the quantum limit of field-effect transistors by using only one electron per switching operation. This was the first demonstration of sub-10nm CNT CMOS devices outperforming their silicon counterparts, said Peng, who expects to develop three-dimensional integrated circuit technology using CNTs, which has the potential to improve the performance of chips by 1,000 times.

To transform laboratory results to products is the next challenge for Peng and his colleagues. In 2015, PKU

established a centre for carbon based nanoelectronics, which, led by Peng, is pushing the industrialization of the award-winning CNT CMOS technology. It has developed a single-chip CPU consisting of 2,600-plus CNT transistors, which outperforms Intel's first microprocessor. "Our CNT

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chips can also be applied in emerging fields such as flexible electronics, shortwave infrared imaging and health monitoring, where silicon technology has no advantage," said Peng, who calls for more industry participation to achieve mass production.

While support from the government and collaboration with companies are important, Peng acknowledges the continued support by PKU, which started investing in CNT research years ago when the potential of the technology was still nascent. This foresight in frontier science and the devotion to interdisciplinary research have contributed to PKU's consistent high rankings among Chinese universities. ■



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