Quantum materials pave the path for synthetic neuroscience

Shriram Ramanathan

Video Abstract

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Abstract

Quantum materials are opening up a realm of possibilities in materials research. Among the best known examples are superconductivity and quantum computing. But that's only the beginning. The same properties that make these materials unique are also enabling researchers to demystify the inner workings of the human brain. So what makes quantum materials well suited for this purpose? Unlike the free-flowing electrons in ordinary conductors or semiconductors, electrons in quantum materials show correlated behavior. That in itself has been the focus of intense physics research. But the upshot for brain research is tunable electronic behavior that can mimic the electronic signaling of neurons and the synapses between them. Most importantly, quantum materials can simulate synaptic plasticity. Plasticity is the biological ability that makes learning and memory formation possible. It's all about timing. Connections between neurons that fire within a short, milliseconds-long time window grow stronger. Firing out of sync tends to weaken links between neurons. Put simply, neurons that fire together wire together, and those that fire apart wire apart. Researchers can recreate this time-dependent behavior electronically using quantum materials. Take vanadium oxide for example. This quantum material can transform from an insulator to a conducting metal under an applied voltage. Under the right conditions, this transition can be co-opted to produce the same patterns of oscillating current observed in firing neurons. Quantum materials can also reproduce the gatekeeping function of the synapses that connect neurons. Samarium nickelate is a good example. Experiments have shown that, when embedded in a transistor-like structure, samarium nickelate can be made more or less conductive—depending on how much oxygen is popped into or out of its crystal structure. And when linked together in an electronic circuit, elements containing this tunable material can dictate how strongly or weakly artificial neurons are correlated under an external stimulus. As currently constructed, artificial neurons and synapses like these bear little to no physical resemblance to the real thing. But they are proving increasingly capable of carrying out the same functions. Ultimately, then, this type of circuitry could hold the same promise for neuroscience and artificial intelligence as homegrown organs do for medicine: the ability to explore important research questions in the lab—all thanks to quantum materials.