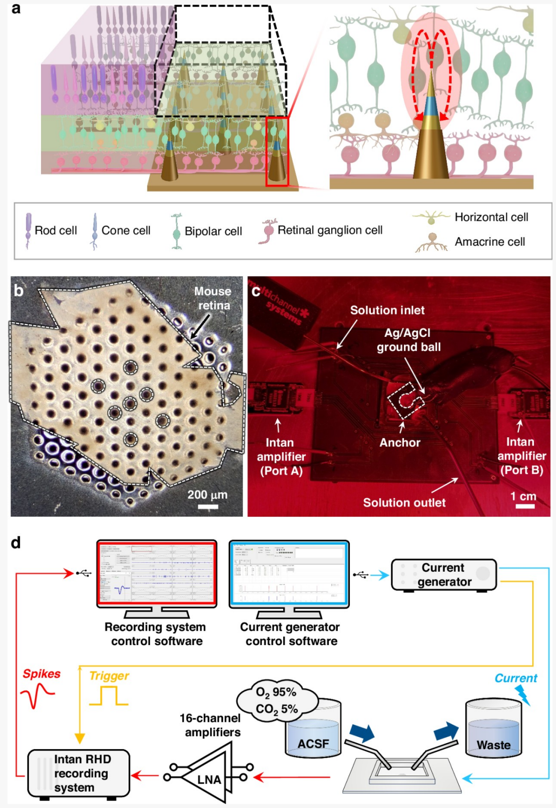
Microneedles that sharpen electric stimulation

GA, UNITED STATES, February 4, 2026 / EINPresswire.com/ -- Precise electrical stimulation is essential for modern neural interfaces, but unwanted current spread often activates off-target cells and limits resolution. A new microneedle electrode design addresses this challenge by integrating a stimulation electrode and a local ground within each individual three-dimensional microneedle. This built-in configuration confines electrical currents to a much smaller region while preserving stimulation strength at the target site. Computational modeling and biological experiments demonstrate that the approach significantly reduces lateral and vertical current spread, leading to more focused neural activation. By improving spatial selectivity without increasing device size or complexity, this strategy offers a compact and efficient solution for high-resolution electrical stimulation in advanced bioelectronic systems.



Schematics and representative images of ex vivo stimulation and neural signal recording from the mouse retina.

Electrical stimulation underpins technologies such as brain–computer interfaces, retinal implants, and cochlear prostheses. As these systems evolve, higher spatial resolution has become a key goal, enabling more natural and selective neural activation. However, electric current naturally diffuses through biological tissue, making it difficult to stimulate only the intended cells. Local grounding techniques can restrict current spread, but in conventional three-dimensional microneedle arrays they often require neighboring electrodes or additional structures, reducing electrode density and design efficiency. These trade-offs have limited progress toward compact, high-precision neural interfaces. Based on these challenges, there is a clear need to develop new electrode architectures that can confine stimulation more effectively without sacrificing spatial efficiency.

Researchers from Seoul National University and the Korea Institute of Science and Technology reported (DOI: 10.1038/s41378-025-01093-0) their findings on November 2025 in Microsystems

& Nanoengineering. The team introduced a three-dimensional bipolar microneedle electrode array that integrates a stimulation electrode at the tip and a local ground electrode along the sidewall of each microneedle. Using simulations and ex vivo mouse retina experiments, the study shows that this design enables highly localized electrical stimulation by suppressing unwanted current spread, offering a promising platform for next-generation neural interfaces.

The core innovation of the study lies in the vertical integration of two electrically independent electrodes within a single microneedle. Unlike conventional arrays that rely on neighboring electrodes for grounding, each microneedle in the new design carries its own local ground positioned just below the stimulation tip. This geometry allows electrical currents to return locally rather than dispersing broadly through surrounding tissue.

Finite-element simulations revealed that activating the local ground redirects current flow toward the sidewall electrode, sharply reducing both lateral spread across the tissue surface and vertical penetration toward deeper regions. Importantly, the current density near the stimulation tip remained comparable to conventional designs, indicating that focality was improved without weakening stimulation strength.

These predictions were confirmed experimentally using isolated mouse retinas. When the local ground was activated, neural responses became confined to a much smaller area around the stimulation site. The number of activated recording channels dropped by more than half, and distant neurons showed markedly reduced firing rates. Spatial heatmaps and distance-dependent analyses further demonstrated that the suppression effect increased with distance, highlighting true spatial selectivity rather than a general reduction in excitability. Together, the results show that embedding local grounding directly into each microneedle provides a powerful and compact way to sharpen electrical stimulation.

"Uncontrolled current spread has long been one of the biggest obstacles to high-resolution neural stimulation," said the study's senior authors. "By integrating a local return electrode directly into each microneedle, we can shape the electric field at its source rather than relying on external grounding strategies. This allows us to stimulate neural tissue more precisely while keeping the device footprint compact. We believe this concept can be extended to many neural interface applications where both accuracy and electrode density are critical."

The bipolar microneedle design opens new possibilities for neural prosthetics and neuromodulation technologies that demand high spatial precision. Retinal implants could benefit from sharper stimulation patterns that improve visual resolution, while intracortical and cochlear interfaces may achieve more selective activation with fewer side effects. Because the architecture is compatible with established microfabrication processes and scalable array layouts, it could be adapted to large-area or high-density devices without major redesign. More broadly, the work demonstrates how thoughtful electrode geometry—not just materials or signal parameters—can fundamentally improve how electrical stimulation interacts with living tissue.

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