国立大学法人豊橋技術科学大学 *Press Release*

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Low-Viscosity Oil Boosts PDMS SlipChip: Enabling Safer Cell Studies and Gradient Generation

< Overview >

Researchers at Toyohashi University of Technology in Japan, in collaboration with the Institute of Translational Medicine and Biomedical Engineering (IMTIB) in Argentina and the Indian Institute of Technology Madras, have advanced the "PDMS SlipChip," a versatile microfluidic device. By using a low-viscosity silicone oil and fine-tuning the fabrication process, they've made the SlipChip more reliable for cell-based experiments and simpler for creating concentration gradients. This breakthrough tackles previous issues like channel clogging and potential harm to cells, opening new avenues for biomedical research, including drug development and sophisticated cell studies.

< Details >

Microfluidic "SlipChips" are clever tools that allow scientists to manipulate tiny amounts of liquid without needing complex pumps or valves. A key feature is their ability to mix different solutions on the chip to easily form step-by-step concentration gradients—ideal for testing how cells respond to varying drug doses, for example, while using minimal precious samples.

PDMS (a type of silicone) has become a preferred material for SlipChips due to its excellent flexibility, gas permeability, and biocompatibility with cells. However, getting the "slip" just right between the PDMS layers using a lubricant (silicone oil) without causing leaks or blockages, and ensuring the PDMS itself is optimally prepared, has been a tricky balance. Traditionally, thicker (high-viscosity) oils were used to prevent leaks, but they often clogged the tiny channels and could be harmful to cells. Thinner (low-viscosity) oils were less prone to clogging, but didn't seal as well.

The research team, led by Professor Moeto Nagai from Toyohashi University of Technology, found a smart solution. They focused on a low-viscosity silicone oil (50 cSt) and optimized the PDMS curing temperatures. Rafia Inaam, the study's first author, explains, "We discovered that how you cure the PDMS affects both how well the layers stick together and the material's overall stiffness. Our 'two-step curing approach'—heating the top layer to 80°C and the bottom to 60°C—struck the perfect balance. This allows for smooth slipping with the low-viscosity oil, without leaks or blockages."

This optimized PDMS SlipChip performs reliably. It maintains a strong seal even with the thinner oil, preventing leaks, and the channels remain clear. When tested with human osteosarcoma cells (a type of cancer cell), the 50 cSt oil showed excellent cell compatibility, with 95% of cells remaining viable—comparable to standard cell culture methods. This overcomes a major concern with previous high-viscosity oils.

"This practical optimization of the oil and curing process has solved a long-standing challenge for PDMS SlipChips, achieving both high performance and safety," says Professor Nagai. "This makes

cell cultures more reliable and also means we can use the SlipChip's powerful ability to create concentration gradients. We believe this will greatly benefit a wide range of research, from fundamental cell biology to applied drug discovery."

< Future Outlook >

The team is now exploring more complex applications for their optimized PDMS SlipChip. This includes using it for sophisticated mammalian cell experiments, such as testing cellular responses to drug concentration gradients created directly on the chip, and studying cell-to-cell interactions. They also envision its use in advanced bio-analytical tasks like protein detection. This improved SlipChip technology could contribute to personalized medicine by enabling more efficient drug screening and advancing cell manipulation techniques in regenerative medicine.

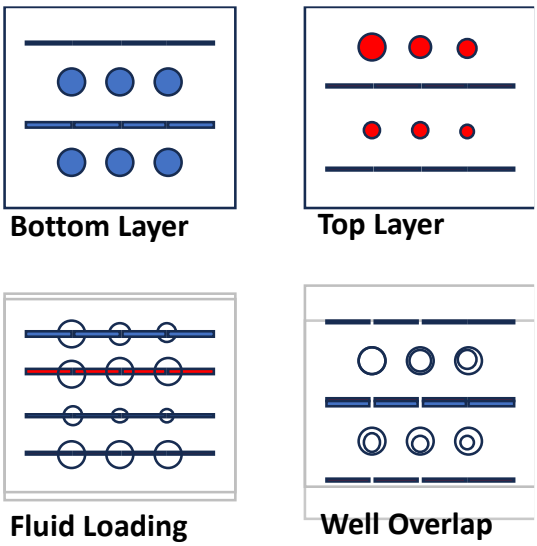

Figure 1: Schematic of PDMS SlipChip Operation. Bottom Layer: Bottom PDMS layer with an array of microwells. Top Layer: Top PDMS layer with an array of microwells, potentially containing different reagents. Fluid Loading: Illustration of the process where distinct solutions are loaded into the microwells of the top and bottom layers. Well Overlap: Depiction of the "slipping" mechanism, where the top layer is moved relative to the bottom layer to align and connect microwells, enabling mixing and the formation of concentration gradients.

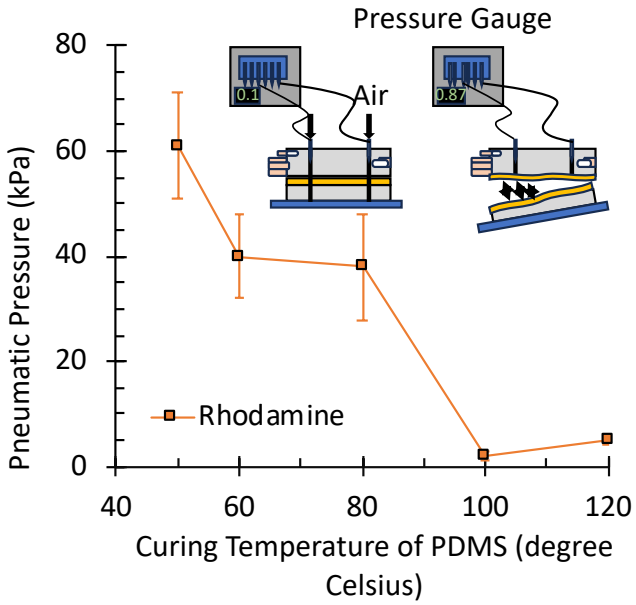

Figure 2: Impact of PDMS Curing Temperature on SlipChip Sealing Strength. This graph illustrates the maximum pneumatic pressure (rupture pressure in kPa) that PDMS SlipChip devices can withstand. Devices were cured at various temperatures (50°C to 120°C) and lubricated with 120 mPa·s silicone oil. The test, using a Rhodamine solution, shows that lower curing temperatures (e.g., 50°C) result in significantly higher sealing strength.

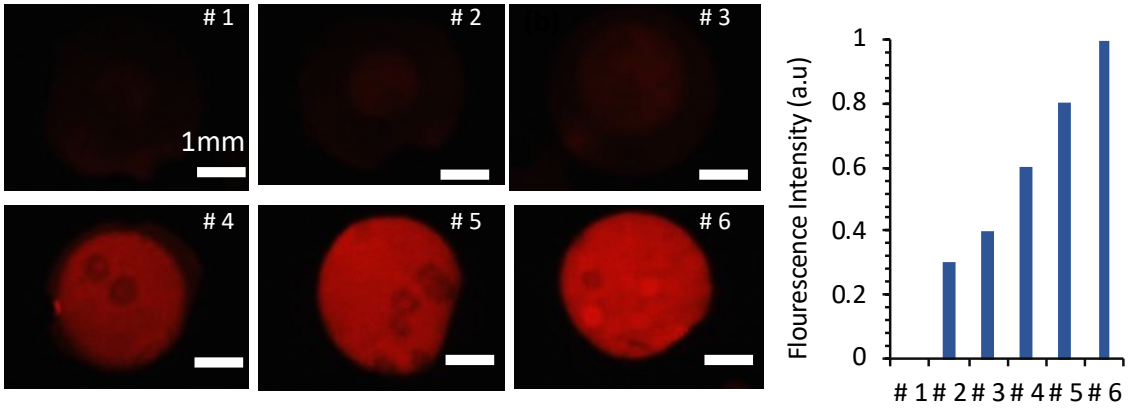

Figure 3: Creating Concentration Gradients with the PDMS SlipChip. (a) Visualization of a stepwise concentration gradient: Fluorescence microscopy images show Rhodamine 6G dye distributed across microwells (#1-6) in the optimized PDMS SlipChip. (Scale bar: 1 mm). (b) Quantitative confirmation: A bar graph shows the measured fluorescence intensity in each corresponding microwell, verifying the controlled generation of the gradient.

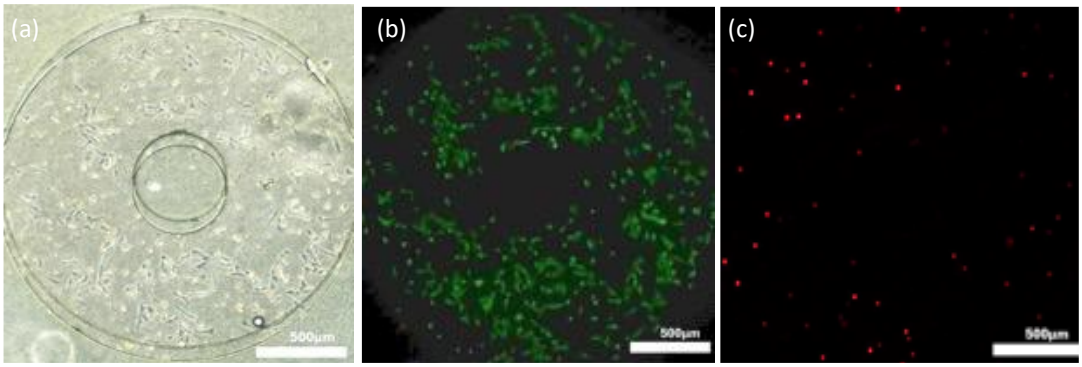

Figure 4: High Cell Viability of Osteosarcoma Cells in the PDMS SlipChip. (a) Micrograph showing osteosarcoma cells cultured within the PDMS SlipChip using 50 cSt low-viscosity silicone oil. (b) Fluorescence micrograph of the same field of view, where live cells are stained green with Calcein AM. (c) Fluorescence micrograph of the same field of view, where dead cells are stained red with Ethidium homodimer-1. The prevalence of green-stained cells indicates high cell viability in the optimized SlipChip. Scale bars: 500 µm.

< Publication Information >

Rafia Inaam, Marcela F. Bolontrade, Shunya Okamoto, Takayuki Shibata, Tuhin Subhra Santra and Moeto Nagai, “PDMS SlipChip: Optimizing Sealing, Slipping, and Biocompatibility Using Low-Viscosity Silicone Oils”, Micromachines, 2025, Vol. 16, Issue 5, 525. DOI: 10.3390/mi16050525 (Published: 29 April 2025)

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