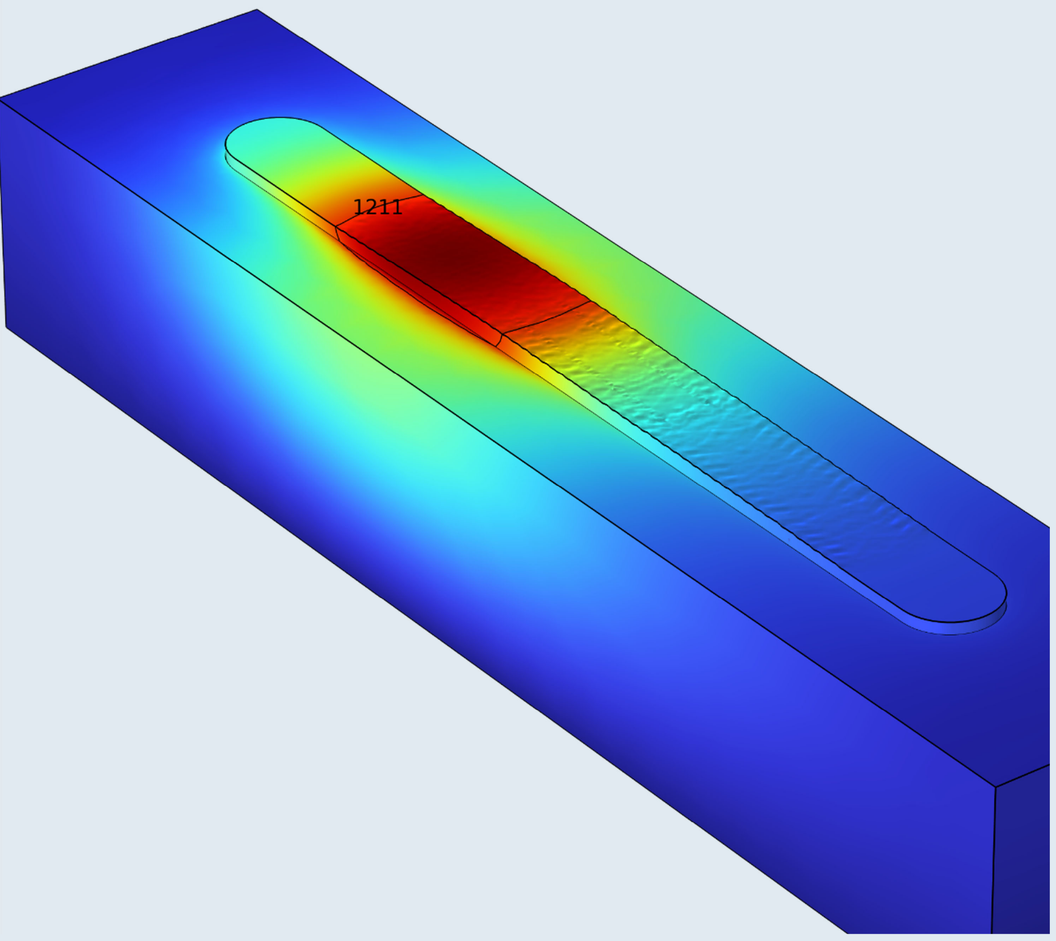


Multiphysics simulation of melt-pool dynamics in laser-induced liquid-phase crystallization of Ge

A custom 3D COMSOL model resolves melt-pool formation, Marangoni flow and solidification in a 500 nm Ge wire on SiO_2.

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Introduction

Laser–induced liquid–phase crystallization (LLPC) forms crystalline Ge wires on insulating substrates, enabling photonic and electronic devices on amorphous platforms. Crystal quality is strongly influenced by the transient melt pool, which is only a few micrometres in size and exists for microseconds, making direct observation extremely difficult. We therefore develop a 3D multiphysics model to resolve melt–pool formation, flow and solidification during laser scanning.

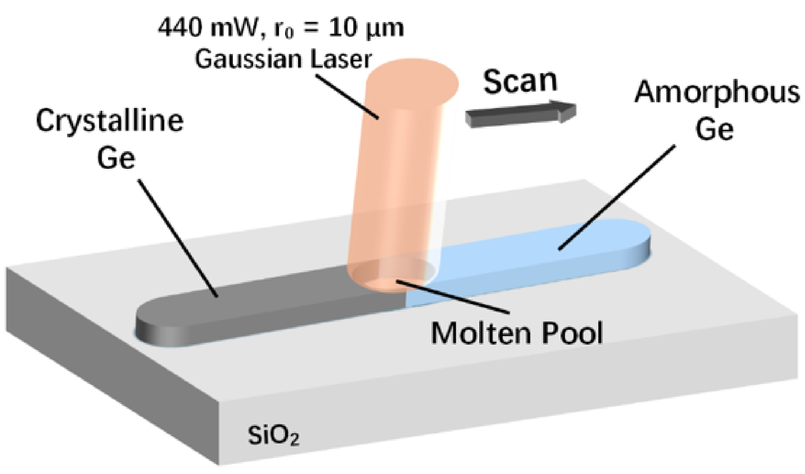


Fig 1. Concept of LLPC. A scanning laser locally melts an amorphous Ge wire on SiO_2, and the molten region resolidifies behind the moving beam.

Model and Method

Geometry: A capsule–shaped Ge wire, 40 µm long, 4 µm wide, and 500 nm thick, is placed on a 60 × 8 × 10 µm SiO_2 substrate. Half of the structure is modeled using a symmetry plane at x = 0.

Physics: A 440 mW Gaussian laser beam with r_0 = 10 µm scans the wire at 100 mm/s. Heat transfer accounts for the latent heat of melting using the apparent heat capacity method, while laminar flow describes convection in the molten Ge. An ALE moving mesh tracks free–surface deformation, and thermocapillary stress at the free surface drives Marangoni flow.

Materials: Temperature–dependent Ge properties are used. The phase transition is numerically smoothed over a 50 K interval from 1161 to 1211 K using the apparent heat capacity method.

Results

Temperature field: The scanning beam produces a comet–shaped thermal field that trails the laser spot, with a peak temperature of approximately 1400 K — approximately 190 K above the Ge melting temperature.

Melt–through: In the section normal to the scan direction, the entire 500 nm wire thickness lies above 1211 K, so the wire melts completely down to the SiO_2 interface. The 1211 K contour continues into the substrate, which remains solid at this temperature.

Melt–pool flow: Since $d\sigma/dT < 0$, surface tension decreases toward the hotter center. The resulting thermocapillary stress drives outward surface flow from the hot center toward the cooler wire edges, accompanied by a slower return flow inside the melt pool.

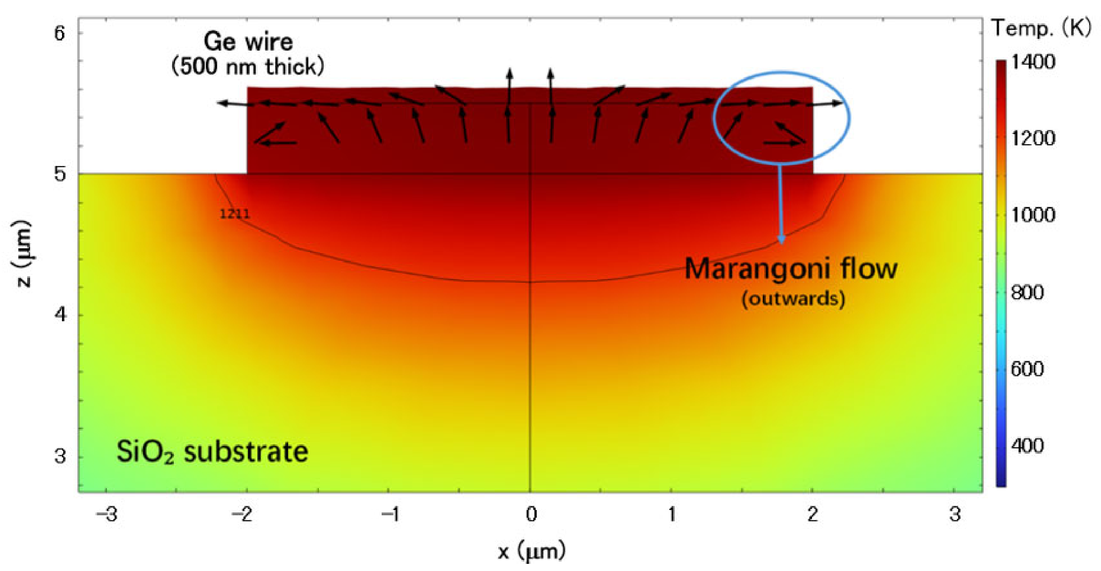


Fig 2. Cross section perpendicular to the scan direction at t = 350 µs. Arrows show Marangoni flow from the hot center toward the cooler wire edges; the whole wire thickness is above the liquidus.

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The Proceedings of the COMSOL Conference 2026 Tokyo より抜粋