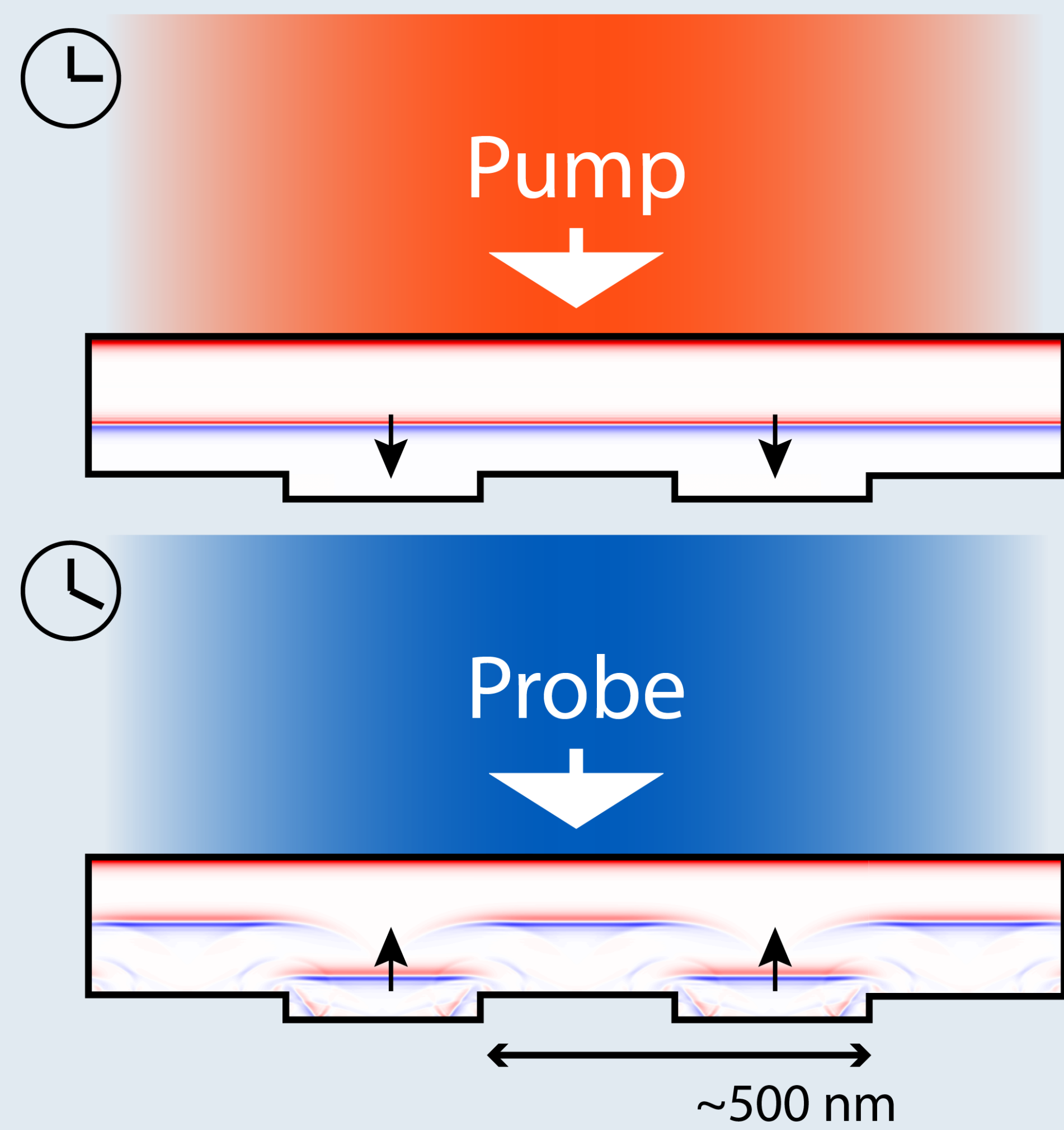


Ultrafast Photoacoustic Characterization of Buried Nanostructures

We model and validate an ultrafast photoacoustic approach using COMSOL Multiphysics® to noninvasively retrieve buried nanostructures with nanometer-scale resolution – surpassing the limits of conventional optical inspection.

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Introduction

Seeing inside opaque materials has always been a challenge, especially when the features are smaller than the wavelength of light. This becomes a serious limitation as modern semiconductor devices shrink and adopt complex 3D designs with opaque layers, where nanometer precision is essential.

Ultrafast photoacoustic offers a solution. By generating high-frequency (100s GHz) acoustic waves with ultrafast laser pulses, it

becomes possible to probe nanoscale features hidden below the surface. Combined with COMSOL Multiphysics® simulations, this method provides nanometer-scale insight into subsurface structures—enabling new possibilities for next-generation semiconductor inspection.

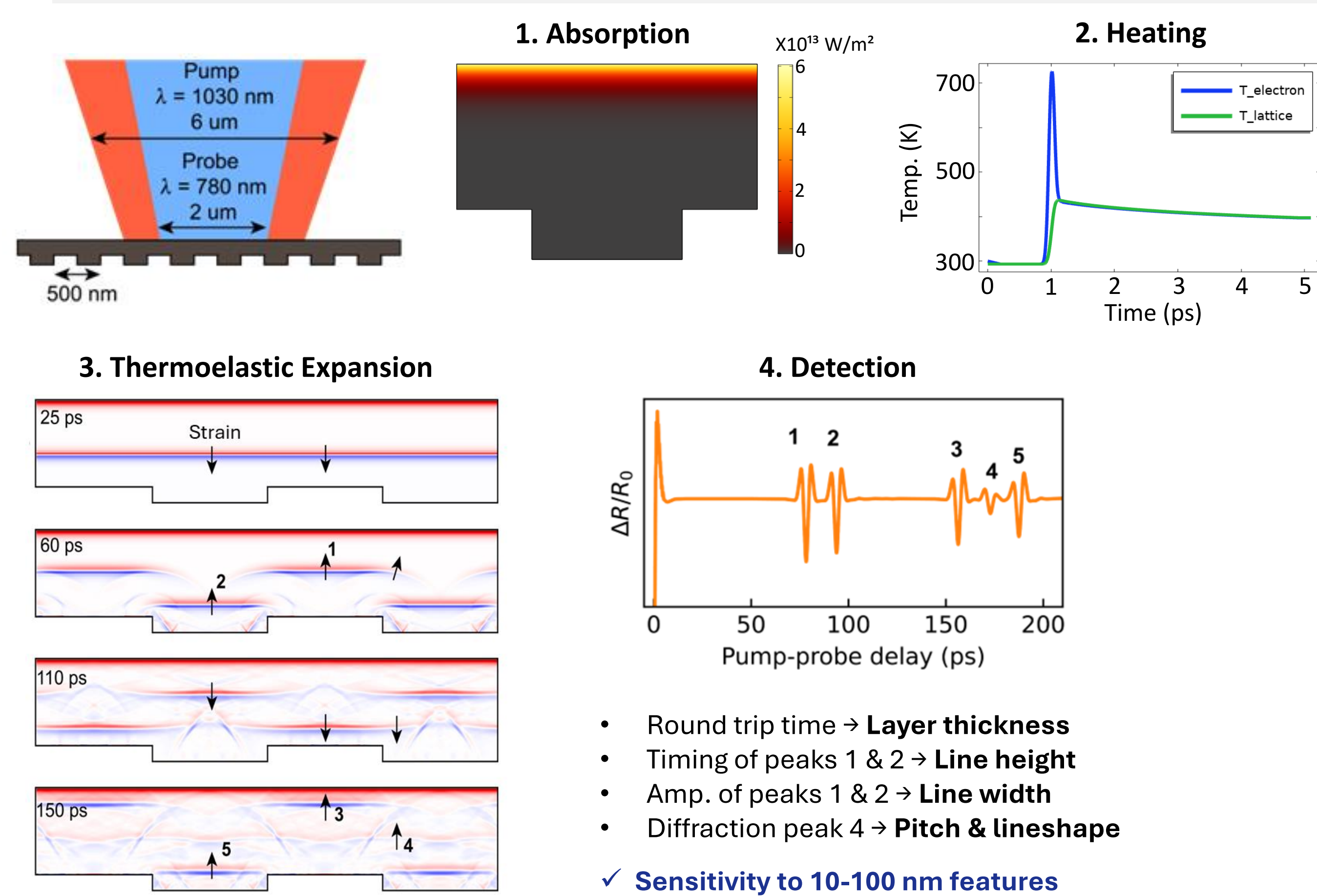


Figure 1. Laser-induced strain pulse interacts with buried nanoscale gratings, enabling time-resolved detection of subsurface features.

Results

- Resolved buried grating linewidth, pitch, and line shape with 10-100 nm sensitivity.
- Achieved high spatial resolution using infrared light ($\lambda=780$ nm) & optical spot sizes of 2–4 μm , far larger than the feature sizes.
- Simulations matched experiments, validating the method.
- Proves potential for high-resolution, noninvasive metrology.

Methodology

A fs laser pulse generates high-frequency acoustic waves that travel through the material and scatter off buried nanoscale features. The resulting strain modulates the refractive index, altering reflectivity, which is measured using a delayed probe pulse. Time-resolved signal reveals subsurface structural information.

Physics Process	COMSOL Interfaces
Laser energy absorption	Radiative Beam in Absorbing Media
Ultrafast electron-lattice heating	Two coupled Heat Transfer interfaces (Two Temperature Model)
Thermoelastic expansion launching acoustic waves	Solid Mechanics (Linear Elastic Material)
Strain induced reflectivity changes	Electromagnetic Waves Frequency Domain

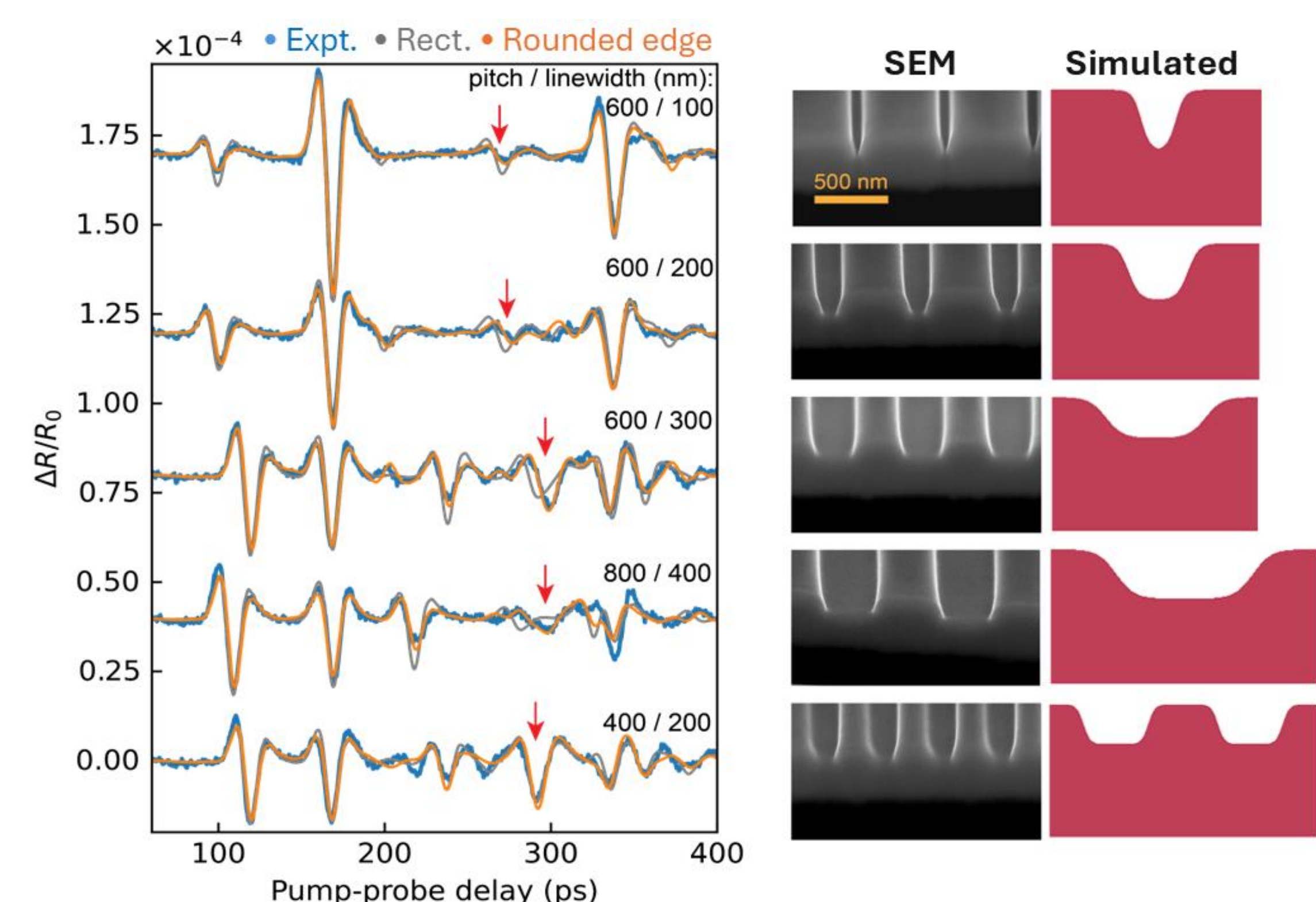


Figure 2. Ultrafast photoacoustic signals reveal sensitivity to duty cycle, pitch, and edge rounding in buried nanoscale gratings.

REFERENCES

1. M Illienko, K Chaudhary, M C Velsink, and S Witte, Characterization of Sub-Optical-Wavelength Structures through Optically Opaque Films Using Picosecond Ultrasonics, *Nano Letters* 2025 25 (22), 8909-8914. DOI: 10.1021/acs.nanolett.5c00800

