FEIC 2026 CONFERENCE PRESENTATION • BIOPHOTONICS & THERMAL MODELING

The Effects of Laser Radiation Interface with Insect Pest Tissues

A Theoretical Framework Supported by MATLAB Simulations

Presented by: Oluwaseyi Bolarinwa

Department of Systems Engineering, University of Lagos.

18th November 2026

Precision Directed-Energy Pest Control

Chemical Limitations

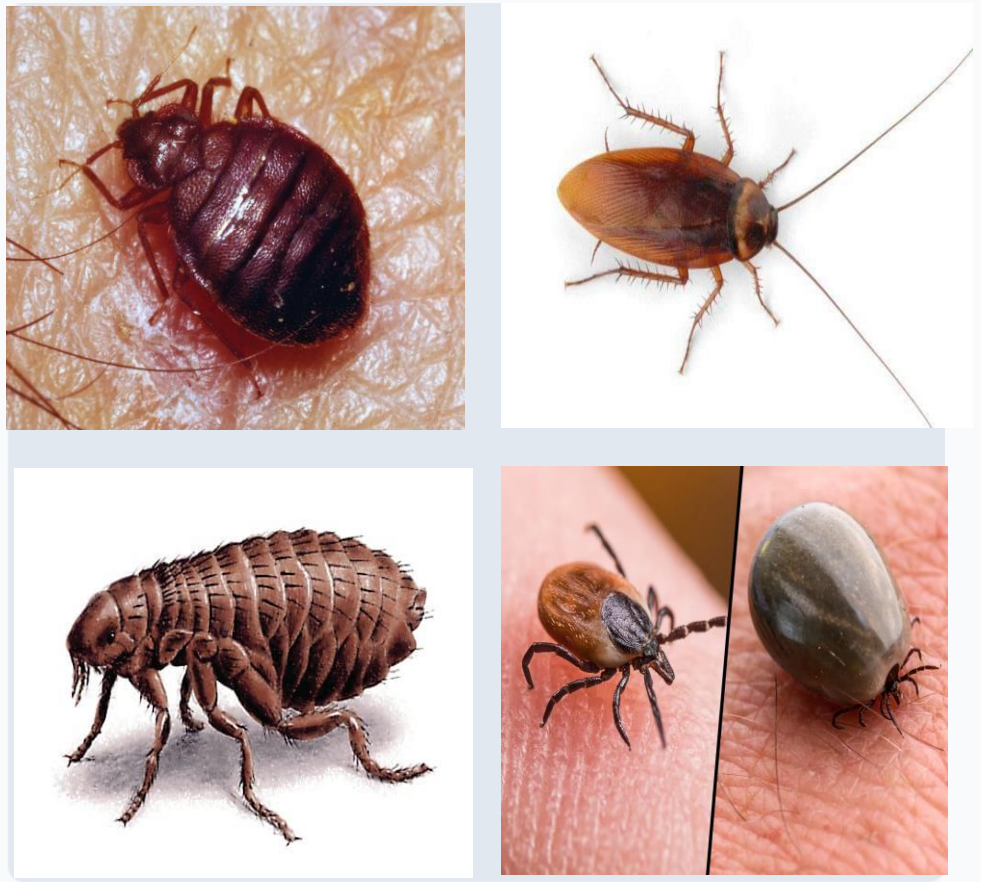
Rising pest resistance and environmental persistence.

Optical Intervention

Targeted non-chemical thermal denaturation via lasers.

Core Challenge

Confining intracellular heat without collateral diffusion.



Britannica Editors (2026, October 16). bedbug. Encyclopedia Britannica. https://www.britannica.com/animal/bedbug

Optical & Thermal Physics Framework

Light-Tissue Coupling

Spectral absorption across 405–1064 nm wavelengths.

Cuticular Penetration

Photon scattering in chitin and internal hemolymph.

Thermal Relaxation

Boundary time governing spatial heat confinement.

Governing Mathematical Equations

Pennes Bioheat Transfer

Micro-scale volumetric heat conduction and laser deposition.

$$\rho C_p \frac{\partial T}{\partial t} = \nabla . K \nabla T + Q_{laser} + Q_{met} + w_b c_b \left(T - T_a \right)$$

Arrhenius Damage Integral

Cumulative thermal injury index (Ω) over exposure time.

$$\Omega(t) = A \int_0^t exp\left(\frac{-E_a}{RT(t)} \right) dt$$

Definition of Parameters

$$\rho C_p \frac{\partial T}{\partial t} = Heat\ storage$$

ρ = tissue density

C_p = specific heat capacity of the tissue

$\frac{\partial T}{\partial t}$ = the rate of change of tissue temperature with time

$$\nabla .\left(K \nabla T \right) = Thermal\ conduction$$

k = thermal conductivity of the tissue.

This term accounts for Fourier's law of heat conduction.

Q_{met} = Metabolic heat generation

Q_{laser} = External laser heat source

$Q_{perfusion}$ = Fluid circulation term

Definition of Parameters

$\Omega(t) =$ *Damage index*

A = Frequency of molecular collision

$E_a =$ *Activation energy*

R = Universal gas constant

$T(t) =$ *Dynamic temperature at coordinate* (x, y, z)

08 • MATLAB IMPLEMENTATION

Parametric Simulation Architecture

405–1064 nm	0.05–20 W	0.5–10 mm	1–1000 ms
Spectral Wavelength Range	Incident Optical Power	Gaussian Beam Diameter	Pulse Exposure Window

Monte Carlo Photon Transport

3D volumetric energy absorption mapping.

FDTD Thermal Solver

Matrix-based transient temperature evaluation.

Continuous-Wave vs. Pulsed Laser Regimes

CONTINUOUS-WAVE (CW)

Broad Thermal Diffusion

Heat Buildup: Gradual radial energy conduction.

Collateral Risk: Surface charring before internal necrosis.

Energy Cost: Higher total fluence required.

PULSED DUTY CYCLE

Targeted Thermal Confinement

Peak Power: Rapid intracellular protein denaturation.

Spatial Control: Pulse duration below relaxation time.

Efficiency: Lower net energy per target.

Result in Command Window

Running Monte Carlo photon transport

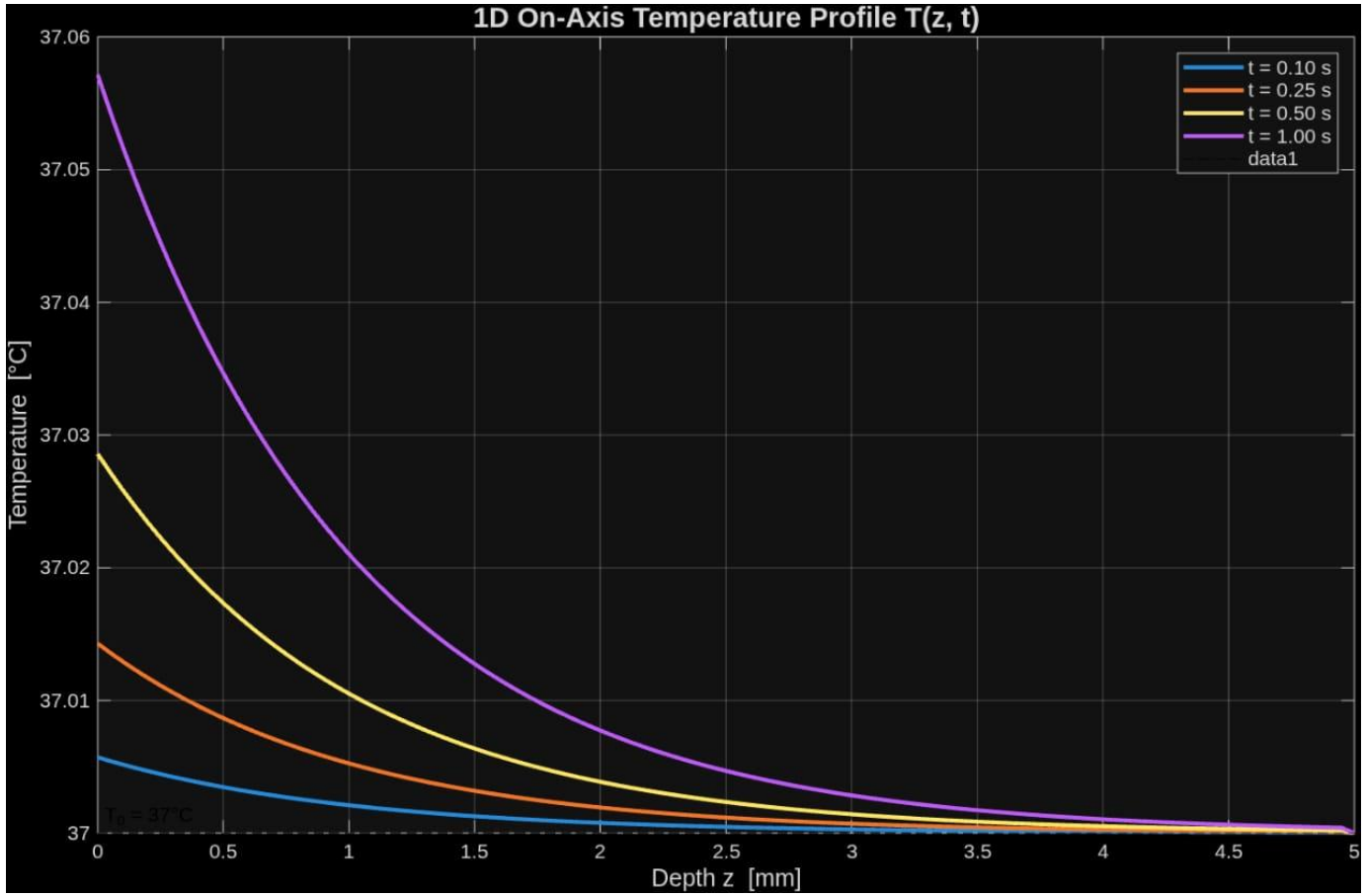
$$\textit{Tallied absorbed energy} : 4.33385 \times 10^{-5}\ J\ (\textit{from an incident energy of}\ 0.0001\ J,\ \textit{giving a tally ratio of}\ 0.4334)$$

$$\textit{Thermal simulation parametres: Tme step}\ (dt) = 9.374 \times 10^{-4} s\ \textit{across}\ 5{,}334\ \textit{total steps}$$

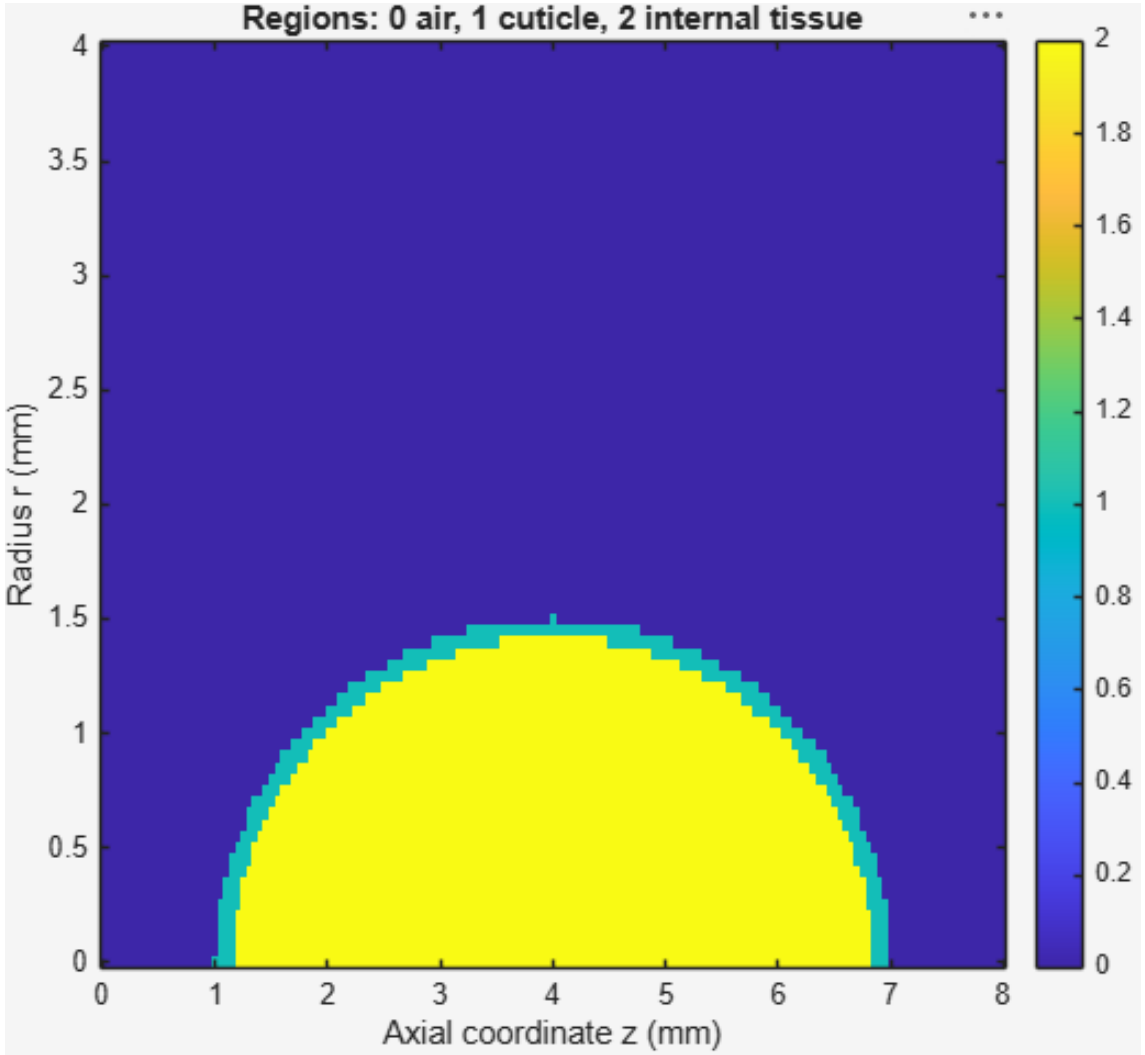
$$\textit{Maximum final body temperature} : 25^{0}C$$

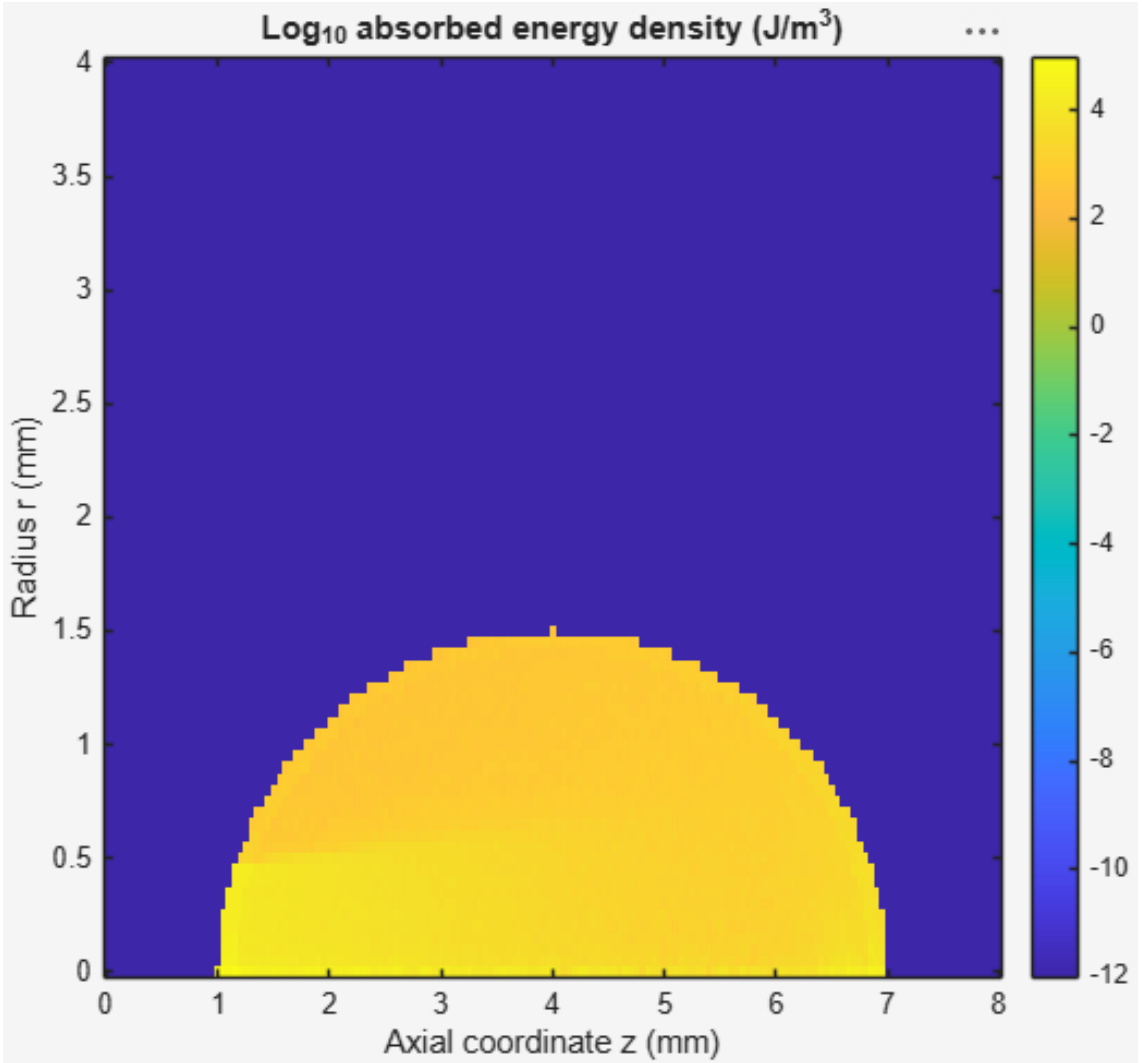
$$\textit{Maximu Peak body temperature} : 25^{0}C$$

Sone dimensional (1D) on-axis temperature profile at different irradiation times (0.10, 0.25, 0.50, and 1.00 s)



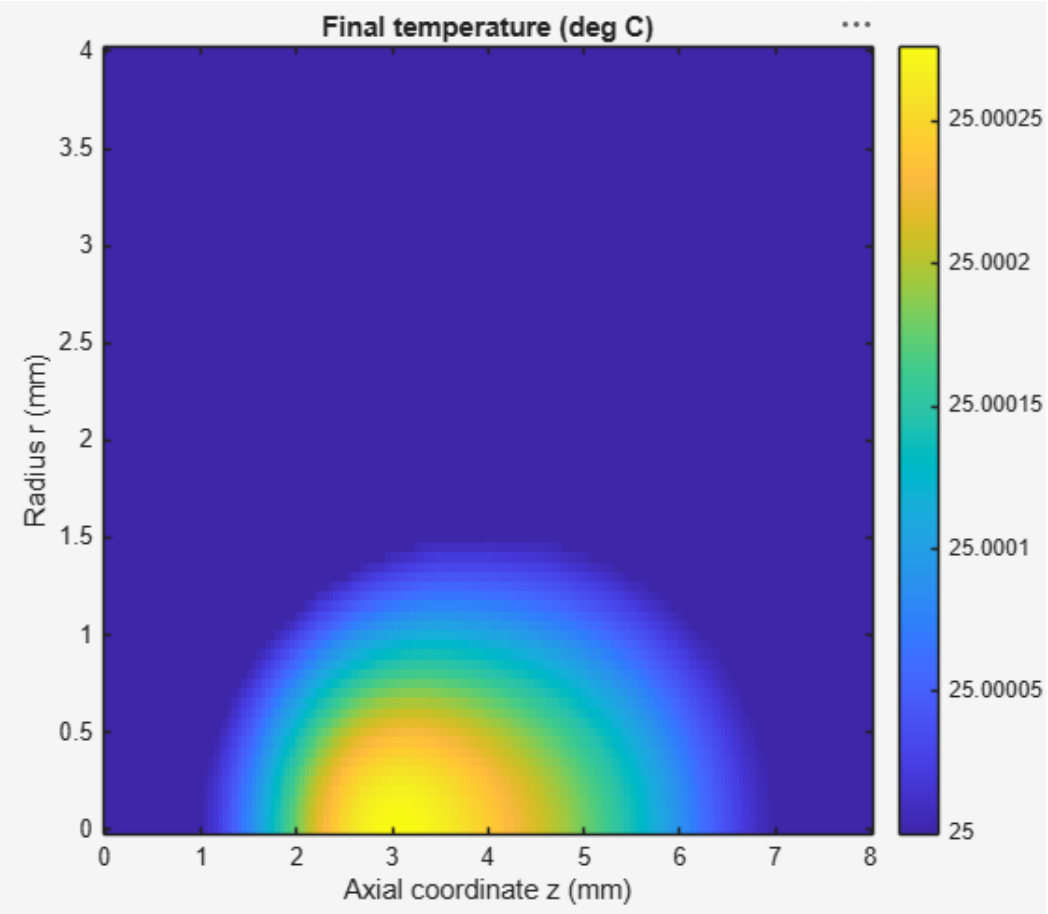
Spatial distribution of Log10 absorbed optical energy density (J / m3) across the cuticle and internal tissue regions derived from Monte Carlo photon transport simulations.

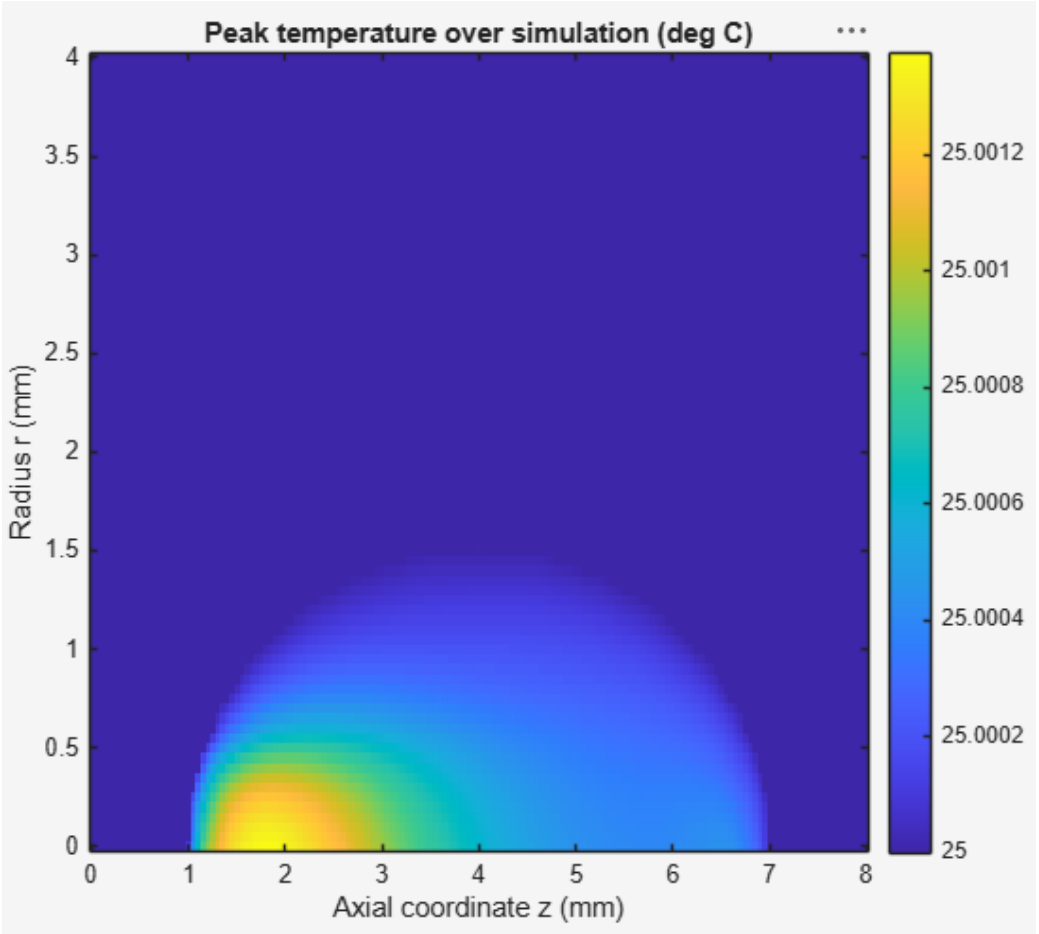




Peak Sub-Cuticular Temperature Profile

Simulated peak tissue temperature (25°C) by penetration depth at 0.05 mW pulsed irradiance (532 nm), with exposure time (2s)





Arrhenius Thermal Damage Kinetics (Ω)

$$\Omega = 4.6$$

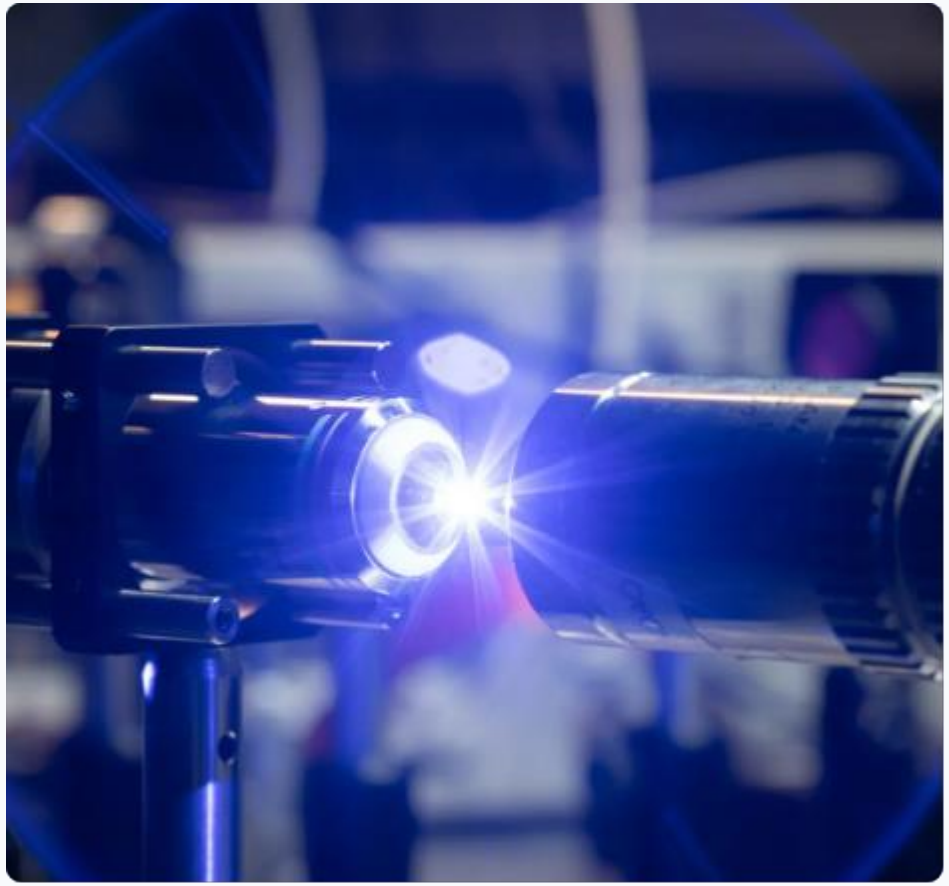
99% Irreversible Cellular Necrosis

Validated Textbook Constants:

- Activation Energy (Ea): 2.57×10^5 J/mol
- Frequency Factor (A): 3.1×10^{98} s^{-1}
- Baseline Exposure Time: 2.0 s
- Incident Energy: 1×10^{-4} J

Damage Index	Cell Death	Exposure Time	Parameters / Status
Ω = 0.5	39% Sub-lethal	t = 2.0 s (Baseline)	Ea = 2.57e5 J/mol A = 3.1e98 s^{-1}
Ω = 1.0	63% Threshold	t = 2.0 s (Baseline)	Irreversible Denaturation Threshold
Ω = 4.6	**99% Lethal**	**t = 2.0 s (Baseline)**	**Complete Necrosis (T_max = 25°C at 1e-4 J)**

Hardware & Engineering Translation



Wavelength Tuning

Matching laser emitters to species-specific cuticle absorption.

Dynamic Duty-Cycle Control

Real-time pulse modulation scaled to target velocity.

Beam Shaping Optics

Sub-millimeter focal spot stabilization for mobile platforms.

SUMMARY & NEXT STEPS

Pulsed Thermal Confinement Enables Selective Pest Necrosis

Next Phase: Histological validation across target household pests.

REFERENCES

Amore, V., Hernández, M. I. M., Carrascal, L. M., & Lobo, J. M. (2017). Exoskeleton may influence the internal body temperatures of Neotropical dung beetles (Coleoptera: Scarabaeinae). PeerJ, 5, e3349. https://doi.org/10.7717/peerj.3349V.

Amore, M. I. M. Hernández, L. M. Carrascal, and J. M. Lobo, "Exoskeleton may influence the internal body temperatures of Neotropical dung beetles (Coleoptera: Scarabaeinae)," PeerJ, vol. 5, Art. no. e3349, May 2017, doi: 10.7717/peerj.3349.

J. L. Capinera, "Internal Anatomy of Insects," in Encyclopedia of Entomology, 2nd ed., J. L. Capinera, Ed. Dordrecht, The Netherlands: Springer, 2008, pp. 1930-1935, doi: 10.1007/978-1-4020-6359-6.

R. Gaetani, V. Lacotte, V. Dufour, A. Clavel, G. Duport, K. Gaget, F. Calevro, P. Da Silva, A. Heddi, D. Vincent, and B. Masenelli, "Sustainable laser-based technology for insect pest control," Scientific Reports, vol. 11, Art. no. 11068, 2021, doi: 10.1038/s41598-021-90782-7.

S. Gunderson and R. Schiavone, "The insect exoskeleton: A natural structural composite," JOM, vol. 41, no. 11, pp. 60-63, Nov. 1989, doi: 10.1007/BF03220386

REFERENCES

Z. Lei, Y. Zhang, Q. Li, T. Shao, L. Sun, K. Wang, Z. Yi, X. Ye, W. Zheng, and P. Wu, “Numerical and Experimental Study on Thermal Damage Induced by Medium-Infrared Laser,” Photonics, vol. 9, no. 11, Art. no. 838, 2022, doi: 10.3390/photonics9110838.

J. R. Lepock, “Cellular effects of hyperthermia: Relevance to the minimum dose for thermal damage,” International Journal of Hyperthermia, vol. 19, no. 3, pp. 252-266, 2003, doi: 10.1080/02656730310000650 42.

Mohamed Abdelrahman, H. G., & Marouf, A. A. S. (2026). Numerical simulation of laser-induced thermal therapy for superficial tumors using COMSOL Multiphysics. Asian Journal of Research and Reviews in Physics, 10(1), 58-74H. G. Mohamed Abdelrahman and A. A. S. Marouf, “Numerical simulation of laser-induced thermal therapy for superficial tumors using COMSOL Multiphysics,” Asian Journal of Research and Reviews in Physics, vol. 10, no. 1, pp. 58-74, 2026.

S. Parker, M. Cronshaw, E. Anagnostaki, V. Mylona, E. Lynch, and M. Grootveld, “Current Concepts of Laser-Oral Tissue Interaction,” Dentistry Journal, vol. 8, no. 3, Art. no. 61, 2020, doi: 10.3390/dj8030061.

J. A. Pearce, “Comparative analysis of mathematical models of cell death and thermal damage processes,” International Journal of Hyperthermia, vol. 29, no. 4, pp. 262-280, 2013, doi: 10.3109/02656736.2013.786140.

REFERENCES

J. Hristov, “Bio-Heat Models Revisited: Concepts, Derivations, Nondimensionalization and Fractionalization Approaches,” Frontiers in Physics, vol. 7, Art. no. 189, Nov. 2019, doi: 10.3389/fphy.2019.00189.

H. Kumar, D. Sagar, S. Verma, C. N. Rajarushi, J. S. Rupali, E. V. Madhuri, G. Godavari, J. S. Pavan, A. Chandel, and G. S. Sujatha, “Heat stress and thermoregulation in insects: Unveiling molecular and physiological responses in light of climate change,” Journal of Advances in Biology & Biotechnology, vol. 27, no. 9, pp. 820-834, 2024.

S. N. Rashid and E. M. Mahdi, “Study the Effect of Nd:YAG Laser on Cowpea Beetle (Callosobruchus maculatus (Fab.)),” IOP Conference Series: Materials Science and Engineering, vol. 454, no. 1, Art. no. 012108, 2018, doi: 10.1088/1757-899X/454/1/012108.

W. Zhou, H. Chang, Z. Jian, Y. Ma, X. Quan, and C. Xiao, “Numerical Simulation of Damage Processes in CCD Detectors Induced by Multi-Pulse Nanosecond Laser Irradiation,” Sensors, vol. 25, no. 15, Art. no. 4851, 2025, doi: 10.3390/s25154851.

Y. Zhang and H. Chen, “Advances in Photonic Technologies for Agricultural Pest Control,” Photonics, vol. 12, no. 3, Art. no. 215, 2025, doi: 10.3390/photonics12030215.

REFERENCES

World Health Organization, “Pesticide Residues in Food,” WHO Fact Sheet, Sep. 15, 2022. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/pesticide-residues-in-food

A. J. Welch and M. J. C. van Gemert, Eds., Optical-Thermal Response of Laser-Irradiated Tissue, 2nd ed. Dordrecht, The Netherlands: Springer, 2011. doi: 10.1007/978-90-481-8831-4.

J. A. Pearce, “Comparative analysis of mathematical models of cell death and thermal damage processes,” International Journal of Hyperthermia, vol. 29, no. 4, pp. 262–280, 2013, doi: 10.3109/02656736.2013.786140.

D. Donoghue, N. Galiatsatos, D. Lawrence, A. Ricci, and S. L. Smith, “Contextualizing Early Urbanization: Settlement Cores, Early States and Agro-pastoral Strategies in the Fertile Crescent During the Fourth and Third Millennia BC,” Journal of World Prehistory, vol. 27, no. 1, pp. 43–109, 2014, doi: 10.1007/s10963-014-9072-2.

THANK YOU FOR LISTENING

ANY QUESTIONS ?