Nanoscale Engineering of Oscillating Systems in Reaction Zones: Towards Smart Energetic Materials

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This research introduces a transformative approach to energetic materials (EMs) through the manipulation of self-organizing nanostructures within reaction zones. By engineering dynamic "burning cells" and energy-driven patterns that emerge from the interplay of chemical reactions and phonon-mediated energy transfer, we achieve unprecedented control over combustion behavior. These nanostructures self-synchronize into collective networks that function as programmable energy exchange channels, fundamentally altering the bulk properties of reaction zones. Our approach integrates multiple control mechanisms, including ultrasound fields, carbyne-enriched energetic antennas for microwave control, plasma-acoustic coupling, and electromagnetic field manipulation. Using 3D printing technology, we fabricate hierarchically structured energetic materials with electromagnetically tuned responses, incorporating reactive antenna structures that enable on-command switching of the burning surface. This advancement addresses the traditional limitations of EMs in active burning rate control, offering precise manipulation of energy transfer pathways and reaction kinetics at the nanoscale. When phonon wavelengths match the characteristic dimensions of microstructures, resonance phenomena create standing wave patterns that drive self-organization into synchronized networks, enabling real-time modification of combustion behavior and energy output. The technology enables tailored energy release profiles for applications ranging from microsatellite thrusters to deep-space propulsion systems.