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Graphene-Based Fire Detection:
A Novel Approach in Fire Safety

"Fire is a global phenomenon that has shaped ecosystems, civilizations, and technological advancements throughout history. However, uncontrolled fires like the Great Fire of London in 1666, the Black Saturday Bushfires in Australia in 2009, and the Palisades Fire in California in 2025, have caused catastrophic damages to the environment, human life, and economies [1]. These widespread impacts highlight the urgent need for effective fire mitigation strategies."

Fire mitigation strategies generally fall into two categories: passive and active. Passive fire protection enhances the fire resistance of structures and materials, preventing the spread of fire. This includes using fire-retardant materials, creating fire defensible spaces, and planting fire-resistant plants. Active fire mitigation focuses on proactively detecting, suppressing, and managing fires through fire warning sensors, firefighting teams, and backfiring techniques. In practice, both active and passive strategies are integrated to create a comprehensive fire safety system. This approach offers significant benefits but it also has certain drawbacks, such as high costs and the need for regular maintenance. Meanwhile, fire alarm systems with fire detection sensors are widely used to detect both domestic and industrial fires. However, traditional fire detection sensors, such as smoke and heat detectors, often struggle with false alarms, slow response times (> 100 s), and sensitivity issues. Therefore, novel fire detection sensors should be developed to address these issues [2].

Graphene and its allotropes have emerged as promising materials for developing advanced fire detection sensors owing to their exceptional mechanical, electrical, and thermal properties. As a single-layer carbon material with a unique 2D structure, graphene offers high strength (1 TPa), excellent electron mobility (250,000cm2/ Vs), and superior heat conductivity (5000W/ mK). Also, its ability to act as a barrier to heat and mass transfer further enhances its potential in fire safety systems. Other graphene family materials like graphite, graphene oxide (GO), and reduced graphene oxide (rGO), also play a crucial role in sensor development. For instance, GO can transition from an insulating to a conductive state when exposed to high temperatures or flames, enabling the design of heat-sensitive sensors with improved detection capabilities (< 5 s) [3]. Graphene-based fire detection sensors can be designed to operate using four different fire detection mechanisms,

- Heat-Induced Conductivity Change: GO transforms into rGO when exposed to fire, decreasing its electrical resistance and triggering an alarm.
- Burning of Insulating Layers: Some sensors use an outer insulating layer that burns away upon exposure to flames, allowing the underlying graphene material to complete the circuit.
- Self-Powered Sensors: Using a triboelectric generator, these sensors generate their own power when exposed to fire, eliminating the need for external energy sources.
- Structural Deformation: Some sensors change shape when exposed to fire, altering electrical properties and setting off alerts.

While highly promising, graphene-based fire detection sensors face limitations such as high production costs, complex fabrication, single-use designs, and limited mechanical durability. Their performance can also be affected by environmental factors like humidity and temperature variations, which may reduce reliability in real-world applications. Therefore, future research should focus on developing cost-effective, eco-friendly sensors with enhanced stability, as well as integrating IoT and AI for real-time monitoring and predictive fire management, ultimately enabling scalable, reliable, and intelligent fire safety solutions.

References

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