Multi-pixel gas sensor platform

FOR A WIDE RANGE OF APPLIANCE AND CONSUMER MARKETS

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How technology helps individuals track air pollutant exposure.

1. Indoor air quality: the invisible factor affecting your health

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AMUSENS is developing a low-power gas sensor platform with enhanced selectivity, addressing a key limitation of existing low-power metal oxide micro-hotplate sensors. This platform combines a multi-pixel approach with artificial intelligence for targeted data analysis. Novel additive manufacturing methods for material deposition (liquid and gas-phase) broaden the selection of usable materials and enable sustainable wafer-scale processing. AI will be used to accelerate material selection and perform data fusion for pattern recognition in gas analysis. The platform's adaptability will be demonstrated through two user case applications chosen in the fields of personal environmental monitoring and health care.

AMUSENS will have a strong economic impact on the highly active segment of gas sensors for the consumer market, and a direct scientific impact on high-level research in the field of gas sensors and artificial intelligence (AI).

1.2. Why tracking air pollutant exposure is important

Tracking air pollution is crucial for increasing awareness and promoting positive behavioural changes within the population. It provides critical information that can empower individuals to take action and drive collective improvements in air quality. Effective monitoring lays the foundation for understanding the sources, levels, and impacts of pollution, but also identifying environmental compartments, behaviours, and life situations that increase exposure to air pollutants.

People are interested in assessing their exposure to air pollution for various reasons. These motivations range from addressing personal health concerns and managing existing conditions to satisfying general curiosity about their environment. Understanding individual exposure can lead to proactive measures to minimize risks and improve well-being.

Air quality assessment is essential in a wide range of environments, including homes, workplaces, schools, public transportation, leisure facilities (such as sports halls, restaurants, bars, and nightclubs), hospitals, and settings involving craft activities (e.g., hair salons, beauty parlours, dry cleaners, etc.). Monitoring pollution levels in these specific environments helps to identify localized pollution sources and potential hot spots and adjusting reliable ventilation and airing practices. Furthermore, given that pollution exposure can fluctuate significantly throughout the day, it is essential to incorporate temporal analysis into monitoring practices to capture accurate and representative data.

1.3. Potential benefits for individuals and communities

The ability to conduct tailored risk analyses offers significant benefits for various populations. By assessing specific environmental conditions, these analyses can provide workers with targeted insights into workplace hazards, enabling proactive safety measures and improved well-being. Similarly, individuals can gain a deeper understanding of potential risks within their homes and frequently visited locations, empowering them to make informed decisions to protect their health.

The citizen engagement, participatory and co-design actions in AMUSENS will increase citizen's knowledge regarding exposure to harmful gases, its potential health risks and mitigation strategies, contributing to behavioural change and quality science education, as well as gender equality following an inclusive participatory approach. The AMUSENS platform cocreated containing scientific and quality information about environmental monitoring and personal healthcare will support these endeavours with the relevant co-design actions including the participating stakeholders plus the citizens. AMUSENS will ultimately impact on the protection and promotion of citizens' health and well-being, contributing to more sustainable communities, reducing their exposure to hazardous emissions.

By introducing a new portable gas sensing device that can give more precise information to citizens, AMUSENS will have an impact for future consumers of these products by increasing citizen's direct awareness and behavioural change towards surrounding pollutants through a portable device to monitor individual exposure to gases.

2. What's in the air? Uncovering hidden indoor pollutants

2.1. Main sources of indoor air pollution (e.g., ventilation, household products, cooking, building materials)

Indoor air pollution refers to the contamination of indoor air, which can lead to harmful health effects (Kodali et al., 2020). Its quality is influenced by various factors, with several key sources contributing to pollution.

Consortium
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9 Countries

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Volatile Organic Compounds (VOCs) and Particulate Matter (PM) are among the most significant indoor air pollutants. Many modern household products—such as paints, lacquers, cleaning agents, furnishings, copiers, printers, adhesives, and permanent markers—emit VOCs, which have been linked to adverse health effects (Maung et al., 2022). Besides, Halios et al. (2022) estimated that approximately 40% of VOCs originate from consumer products and occupant activities.

Cooking is one of the major contributors, producing both particulate and gaseous pollutants. Sun and Wallace (2021) estimated that cooking accounts for approximately 22% of daily PM2.5 exposure. Similarly, combustion from heating or smoking releases carbon monoxide, nitrogen dioxide, particulate matter, and polycyclic aromatic hydrocarbons, with emissions varying by fuel type (Angell et al., 2005).

Cleaning products and household activities contribute to indoor pollution by releasing VOCs and resuspending particles during use (Angell et al., 2005; Abt et al., 2000). Additionally, building materials and furniture continuously emit VOCs and formaldehyde, particularly in newer constructions (Angell et al., 2005; Maung et al., 2022). Human activity further exacerbates pollution by resuspending particles and increasing carbon dioxide levels (Abt et al., 2000).

Finally, outdoor pollutants infiltrate indoor spaces through building envelopes and attached garages. Poor ventilation can lead to the accumulation of contaminants, further degrading indoor air quality.

2.2. Potential health effects of prolonged exposure to indoor pollutants

Indoor air pollutants—including biomass smoke, particulate matter, nitrogen dioxide, volatile organic compounds (VOCs), formaldehyde, and environmental tobacco smoke—are linked to various adverse health effects (Angell et al., 2005; Bruce et al., 2002; Hulin et al., 2012).

Several studies report acute respiratory impacts across different population groups, including lower blood oxygen saturation, increased airway inflammation (evidenced by elevated FeNO levels), reduced lung function, and asthma exacerbations (Maung et al., 2022; Vardoulakis et al., 2020). Short-term exposure to VOCs and nitrogen dioxide, for instance, has been associated with upper airway symptoms and asthma in children (Maung et al., 2022).

Beyond respiratory effects, exposure to indoor pollutants has been linked to systemic health outcomes, such as cardiovascular effects, reduced birth weight, increased infant and perinatal mortality, and a heightened cancer risk—including leukaemia and nasopharyngeal cancer (Angell et al., 2005; Bruce et al., 2002; Maung et al., 2022; Vardoulakis et al., 2020).

Certain groups appear particularly vulnerable, including children, pregnant women, individuals with pre-existing respiratory conditions, and women—especially in developing countries—who are disproportionately exposed to indoor pollutants (Angell et al., 2005; Bruce et al., 2002).

2.3. Limitations of current indoor air quality monitoring methods

Current indoor air quality (IAQ) monitoring methods face several limitations. Traditional approaches rely on expensive, invasive instruments that are impractical for widespread use, leading to small-scale or short-term studies. Low-cost gas sensors (LCGS) have emerged as a potential solution, offering continuous monitoring and high-resolution data collection. However, LCGS have inherent limitations in data quality and may not meet regulatory standards for indoor monitoring (Ródenas García et al., 2022). Challenges include addressing spatial and temporal heterogeneity of indoor pollutants, identifying pollution sources, and integrating outdoor air quality data (Higgins et al., 2024; Kumar et al., 2016). Despite these limitations, LCS show promise for improving IAQ monitoring by enabling long-term, multi-room measurements and facilitating the development of innovative methodologies.

Among these innovative approaches, LCGS can be integrated into wearable devices and used as personal exposure sensors. Unlike fixed monitoring stations (including LCGS when deployed statically in specific locations), these wearable devices track individuals through the diverse microenvironments they encounter. They provide crucial data not only on the specific pollutants and concentrations to which individuals are exposed but also, critically, on the duration of these exposure events. This capability allows for a more precise assessment of personalized exposure doses, which can differ substantially among individuals, even those occupying or transiting through the same general locations, thereby offering a deeper understanding of individual IAQ-related health risks. This solution however requires devices with sufficiently low power to guaranty its autonomous over the monitoring period.

Future research should focus on improving sensor technologies, encompassing advancements in both stationary LCGS and personal exposure sensors, as well as enhancing data interpretation, and developing appropriate regulations to address IAQ risks (Kumar et al., 2016).

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2.4. Concept of personal air quality monitoring

Personal air quality monitoring has gained significant importance due to the health risks associated with air pollution. It not only empowers individuals to make informed, healthier decisions but also provides valuable data for policymakers to design more effective air quality control measures in urban, industrial, and rural areas (P. Oluwasanya et al., 2019). This approach marks a substantial shift from traditional fixed-station monitoring to more personalized and comprehensive air quality assessment.

Air quality monitoring (AQM) involves assessing the levels of common air contaminants (Salva et al., 2023). Given that most people spend over 90% of their time indoors (Jiang et al., 2011), personal monitoring can offer crucial insights into how individual exposures correlate with residential air pollution estimates (Nieuwenhuijsen et al., 2015).

A growing body of evidence indicates that indoor air can be two to five times more polluted than outdoor air, even in highly industrialized urban areas (Park et al., 2023). Portable air monitors represent a promising strategy, as they enable citizens to collect air quality data in various locations, including indoor spaces (Park et al., 2023). Despite awareness of pollution in indoor spaces comes into conflict with the sense of safety they provide to their occupants. However, once awareness is established, the occupant realizes that through simple actions, the pollution levels in their indoor environment may be reduced and occupants may directly benefit from the positive impact of their actions on their health and well-being.

3. Defining User Needs for the sensor

3.1. Development of sensor (AMUSENS)

Gas sensors are crucial in the personal and industrial monitoring to analyse personal exposure to air pollutants or to critical gases, to control product quality such as in the food industry, and in health care by analysing gases from the human body. These applications require miniaturized low power and low-cost gas sensors with good gas selectivity to be integrated in personal devices, in product packaging or in widely distributed sensor networks. In addition, sensor development must also be guided by end-user needs and contexts of use, ensuring that technical features align with real-world expectations and usability.

Beyond these technical specifications, miniaturization also addresses key ergonomic and acceptability concerns: for wearable devices to be truly adopted, users must be able to ‘forget’ they are carrying them, while still being able to consult the information when needed. Sensor development must therefore be guided not only by performance metrics but also by real-world usage contexts and end-user expectations.

3.2. Integration with sensor platform (AMUSENS)

This integration process involves sensor development, database creation, AI-driven material selection, and user-centred validation through real-life applications.

The sensing platform will incorporate four sensor chips, adapting existing sensing technologies to improve performance. A common testing chamber will be designed to ensure minimal latency and precise response time measurement. Robustness tests will be conducted to assess the impact of environmental variations, like temperature and humidity. The platform will be further enhanced with an AI algorithm for material selection and gas sensor data analysis.

A structured database will be created to store gas sensing responses of different materials under various conditions. AI-based algorithms will process the database to identify the optimal material combinations for gas detection. The goal is to determine the minimum set of materials necessary for reliable VOC detection, optimizing sensor performance through advanced selection methods like boosting.

3.3. Survey conducted to understand concerns and expectations

The survey gathered participant background (education, occupation) and monitoring preferences, including time spent indoors, reasons for assessing gas exposure, monitoring experience, preferred devices, and essential monitoring parameters.

Additionally, the survey evaluated the monitoring system and gathered feedback on individualized monitoring needs, sensor usability (recharging), interest in risk analysis, data presentation preferences, and factors influencing data reliability and accuracy.

3.4. User-Centred Requirements for Real-Life Application

The AMUSENS sensor development process is not only grounded in technical excellence, but also in a strong user-centred philosophy, ensuring that solutions are designed with and for the people who will ultimately use them. This approach is inspired by the principles of User-Centred Design (UCD) and Design Thinking, which place human needs, behaviours, and experiences at the heart of innovation.

User-Centred Design, as formalized by Norman and Draper (1986), provides the practical framework to implement this philosophy (Chammas et al., 2015). It emphasizes user involvement throughout the development cycle, from early exploration of needs

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to validation of final solutions. Successful User-centred Design results in tools that are intuitive, relevant, and usable in the context of real-life activities (Abras et al., 2004; Lanter & Essinger, 2017).

In AMUSENS, this means end-users—such as workers, school staff, office employees, or citizens—are not only consulted but engaged as co-creators through co-design activities. Their feedback on aspects like usability, ergonomics, preferred form factors (wearable vs. fixed), and trust in data reliability informs the entire development cycle.

This inclusive and iterative approach ensures that the sensor responds to practical needs, supports informed decision-making, and fosters user trust—maximizing both usability and societal value. Moreover, leveraging co-creation and testing with real-life prototypes will allow AMUSENS to adapt to diverse contexts of use while addressing the unique concerns and preferences of each user profile.

4. Expected benefits of the technology

4.1. Personalized awareness of air quality levels

The capability of analysing gaseous species diluted in air can bring unprecedented benefits to everyday life, enabling real-time monitoring of indoor and outdoor air quality. Gas sensors have the potential to raise awareness of harmful gas exposure by continuously assessing air quality, helping individuals understand the risks they face and promoting proactive health measures. By integrating gas sensors into electronic devices, citizens will have access to personalized data on air quality, helping them stay informed about the environmental conditions around them. This awareness is crucial for improving public health and reducing exposure to pollutants in various environments, including homes, workplaces, and public spaces.

The co-design of these sensors, based on multi-pixel gas sensor platforms, requires close collaboration with end-users to ensure the technology meets their needs and promotes effective use. The involvement of Social Sciences and Humanities (SSH) experts is key in understanding the human dimension of these sensors, enhancing user experience, and ensuring the technology benefits individuals and society.

4.2. Support for informed decision-making (e.g., route choices, ventilation needs)

The ability to monitor gaseous species in the air enables informed decision-making in various contexts, from healthcare to everyday life. Gas sensors can provide real-time data on air quality, which individuals can use to make decisions about their environment, such as choosing safer routes to avoid pollution or adjusting ventilation needs in a building. In addition, these sensors can play a critical role in industries like food production or fitness, where air quality and gas emissions can directly impact product quality and human health.

By collaborating with end-users during the co-design process, gas sensors are developed with practical usability in mind, ensuring they are intuitive and effective in daily decision-making. The integration of these sensors into consumer devices can empower individuals to make data-driven decisions, improving their well-being and the overall quality of life. Furthermore, the technology can help raise awareness of the risks associated with harmful gas exposure and demonstrate the benefits of new gas sensor technologies like the ones developed in AMUSENS, benefiting both individual users and broader societal health.

5. Next Steps in AMUSENS

5.1. Ongoing sensor development and testing

Sensor modules will be integrated into wearable devices. These devices will be tested in field campaigns with household workers to assess exposure to indoor pollutants. The study will combine quantitative and qualitative data to evaluate the system's potential in influencing behavioural changes.

5.2. Refinement of user experience and data accessibility

To ensure the platform meets real-world needs, we will integrate input from end-users and citizens through a human-centred co-design approach. This process will align technical requirements with user expectations and practical applications.

To do this, a workshop focused on user-centred design and usability testing for the AMUSENS sensor will take place, exploring key aspects such as:

- **User Needs & Context of Use** – Understanding motivations for monitoring air quality (health concerns, curiosity, research) and identifying the most relevant settings (workplaces, homes, schools).
- **User Journey & Interaction** – Examining how users engage with sensors in different environments (fixed vs. wearable devices), and how real-time data influences decision-making.
- **Sensor Design & Features** – Gathering preferences on form factor, single vs. multi-parameter measurements, real-time data visualization, and ergonomic considerations.

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- **Data Trust & Interpretation** – Addressing concerns about accuracy and reliability, and exploring ways to build trust through calibration, certification, and clear communication (e.g., using familiar comparisons like weather apps).

This collaborative approach will help shape an intuitive and effective sensor that truly meets user needs.

5.3. Future pilots and validation efforts

The project will deliver at least 10 multi-pixel sensor devices with different material combinations for integration into final application cases. These efforts will drive AMUSENS towards validating a versatile and scalable gas sensing platform, ensuring its relevance for both environmental exposure monitoring and health applications.

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