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Review Article

Review On Micro-Gas Chromatography System For Analysis Of Multiple Low-Concentration Volatile Organic Compounds

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ABSTRACT

The device can identify organic compounds (VOCs) in indoor air or in a monitoring setting where varying quantities of VOCs are required immediately because of the hazards associated with VOCs and their potential use as non-invasive biomarkers. The human body. The equipment used for the qualitative and quantitative measurement of various volatile organic compounds (VOCs) can be replaced with more conventional tools in the field of micro gas chromatography (μ -GC). The microelectromechanical systems (MEMS)-based micro or micro detector, the micro gas concentration, and the μ -GC column make up the three primary parts of the system. In order to investigate the μ -GC advancement's operational potential, efficacy, and integration process, this evaluation looks at the design, content, and literature on three different themes. The difficulties that must be overcome in order to commercialize this technology are also covered. Food, tastes and smells, medicine, and forensic science are just a few of the sectors that are interested in volatile organic compounds, or VOCs. Environmental chemistry is the primary field of study with respect to tropospheric ozone generation, stratospheric ozone depletion, and the brittleness of organic molecules because of their harmful and cancer-causing impacts on human health. Generally acknowledged norms: based on the definition of VOC. VOCs and organic solvents are frequently used interchangeably in discourse. In the US, the phrase "volatile organic compounds" (VOCs) refers to any organic component that is thought to be involved in the creation of ozone. Some phrases have more specific definitions and are derived from a mix of chemical and physical attributes, such the heat content and chemical formula.

INTRODUCTION

Volatile organic compounds (VOCs) have been linked to a number of respiratory conditions,

hospital admissions, and familial diseases exhibiting symptoms including headaches, nausea, and exhaustion. [1,2] Numerous items that are

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frequently found indoors, such as paint, wallpaper, adhesives, cosmetics, furniture, and petroleum products, release these volatile organic compounds (VOCs). VOCs, especially at tiny doses, have the potential to have major long-term impacts, particularly for newborns and those with underlying medical disorders. It is important to remember that the International Agency for Research on Cancer has categorized benzene and trichlorethylene as Group 1 carcinogens. [3,4] Specifically, Research has looked into exhaled breath as a bodily secreted metabolite and utilized to identify very fatal illnesses like lung cancer. However, approximately a thousand organic chemicals may be found in exhaled breath, and high-performance equipment is needed for an accurate VOC measurement. For the purpose of detecting different volatile organic compounds (VOCs) in ambient and exhaled air, the thermal desorption-gas chromatography mass spectrometry approach is essential. [5,6,7,8] This review's objective is to examine analytical techniques for gas chromatography (GC)-based VOC determination. Whether in liquids, solids, or gases, the first step in any VOC investigation is typically to determine the initial concentration of the compounds. Nowadays, information is accessible on a wide range of subjects, such as distillation, stir bar motion extraction (SBSE), solid phase microextraction (SPME), cryogenic concentration, solvent extraction, static and dynamic headspace, and solid adsorbents. Numerous technological criteria, such as sublimation, are part of it. [10,11, 9] Specialists can offer in-depth analyses of these subjects for group debate. An environmental evaluation was carried out by Clement et al., Fox, Richardson, DeWolff, Van Langenhoven, and Helmig. Wine, grain volatiles, and food scents are included in the primary examination of fragrances. Furthermore, several evaluations concentrate on particular pre-treatment techniques such the agency

appropriateness of the headspace technique, sorbent capture, and SPME. Water impact is a significant issue that has to be resolved. Strategies including choosing hydrophobic adsorbents, adding hygroscopic salts, employing water-absorbing polymers like Nafion, and introducing dry processes have all been investigated in recent studies on water removal. [12,13,14,15] Coupled analytical instruments, like TD→GC→MS, are frequently big, costly, labor-intensive, and challenging to run, which makes them challenging to utilize. Complex procedures like model design, modeling, transportation, and analysis can take a lot of time, money, and effort. Most notably, VOC contamination in the field cannot be detected by TD-GC-MS analysis, nor can it be used to quickly identify hazardous VOCs. This tiny gadget detects trace amounts of several kinds of organic volatile compounds (VOCs) and metabolites in the atmosphere. MEMS-based equipment is applied in the system μ -GC. A micro gas preconcentrate and a tiny gas chromatograph (μ -GC) column both (μ -PC) are among its primary components, which improve measurement and get around restrictions. [16,17] To create and partially integrate these products for the discovery of certain organic molecules, a great deal of study has been done. These elements, as well as a combination of them are employed in the innovative μ -GC system developed by Zeller's group at the University of Michigan in 2005, the hybrid MEMS gas chromatograph. Many methods that can detect a broad variety of volatile organic compounds (VOCs) that have an impact on air quality have been developed since then. This study will evaluate newly developed μ -GC systems directly, while prior reviews concentrated on in-depth research and comparison of important products like μ -GC. It will also explain how physical considerations can overcome some shortcomings. Furthermore, for a deeper comprehension of μ -GC systems, this paper investigates how these



essential elements can take the position of TD-GC-MS. As a result, many of the features of the recently released μ -GC systems are known to implemented utilizing the device integration and setup procedure, as well as the features and performance assessments. The literature, design, and principles have been studied for the basis items. Lastly, important topics concerning the marketing and commercialization of μ -GC systems are included in this study. [18,19, 20]

Micro Gas chromatography system [MGCS]

As a minor portion of the TD-GC-MS system for multiple sclerosis, the μ -GC system's setup and analysis procedure is comparable to that of the TD-GC-MS system, which is used to Determine the low concentrations of a number of volatile organic compounds (VOCs). This study breaks down the three main commercial TD-GC-MS systems now in use and explains how each μ -GC system component may be altered turned low-concentration volatile organic compounds (VOCs) into high-concentration VOCs, increasing the sensitivity of TD-GC-MS. Thermal desorption

(TD) and pre-concentration are the two steps of the procedure. They are very porous and have a high specific surface area. adsorption materials such as carbon nanotubes, activated carbon, zeolite, activated alumina, and graphene gas may be adsorbed into TD tubes during the pre-concentration process. The pump keeps absorbing over time high VOC s within a TD tube. VOCs that have been adsorbed to the material in the TD tube during the TD process are quickly released when heated, resulting in a concentration that is significantly higher than what was originally collected. -In actuality, the GC system is a scaled-down variant of the TD system, developed with MEMS technology. The μ -PC sheet incorporates cavities with various configurations to enclose and confine the adsorbent. These units have connections to the intake and output, which permit the passage of volatile organic compounds (VOCs) throughout the course of the study pre-concentration phases, respectively. [21, 22, 23, 24,]

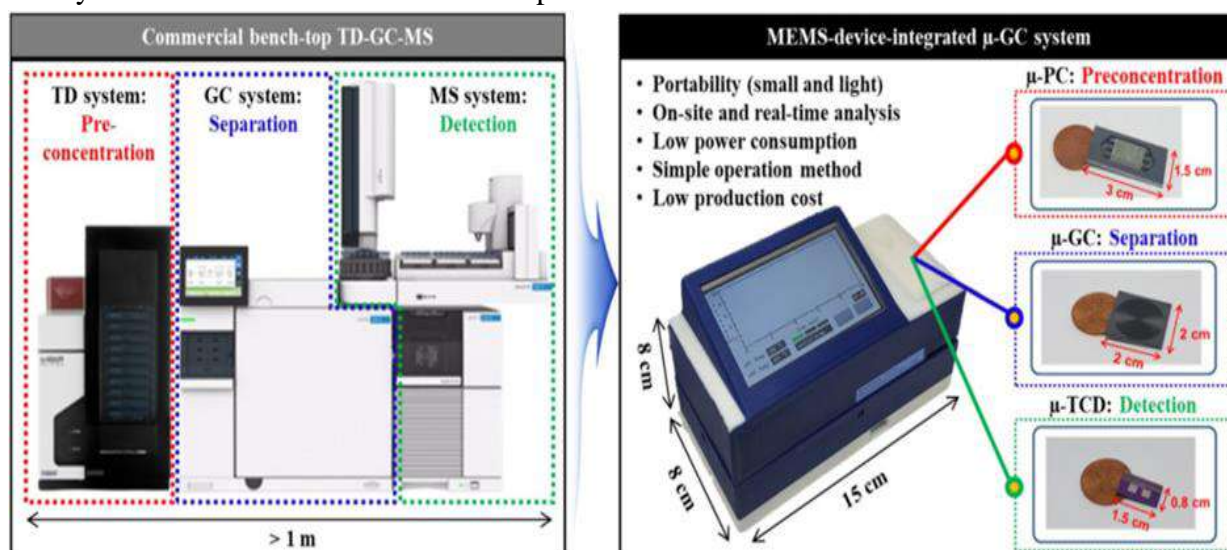


Figure The TD-GC-MS apparatus for commercial use and a μ -GC system combined with MEMS devices Furthermore, the heating pattern is frequently positioned below the plate or, in the case of TD devices, the wire is completely encircling the plate to generate heat. The GC system for TD-GC-MS consists of an oven to enhance troubleshooting, independently choose, and amp up GC operations, as well as a GC column filled or covered with a stationary phase in order to guarantee mixing of

the VOC mixture at various concentrations throughout time. Lately, there has been a lot of use of capillary oil chromatography columns covered with thin stationary phases, mostly made of polydimethylsiloxane (PDMS), which is easily modifiable with different functional groups. This is caused by the packing line's poor quality, the variation in fixed positions, and the low plate number (representative performance on the one hand) and inadequate separation as a result of stress. [24, 26]

The material in question is a thin, 15–60 m long fused silica tube having a diameter of 0.1-0.53 mm. capillary gas chromatography column. The biggest factor influencing separation, other from stationary phase, is line length. To attain certain GC system dimensions in centimeter-scale MEMS devices, the deep ion etching (DRIE) approach is necessary. On centimeter-scale plates, lines tens to hundreds of microns broad are stretched using DRIE to produce 0.3 to 2 m lines. Typically, the front part of the μ -GC apparatus is extended to create glass-lined channels, which are then sealed via anodic bonding to restrict liquid flow to one direction at the intake and outflow. In addition, the heater type that will replace the GC furnace is located in the back. As temperature has a big influence on separation, resistive temperature detectors, or RTDs, are crucial in μ -GC RTDs but are also often utilized in μ -PC RTDs. [27, 28]

Gas is kept constant at the same retention time (RT) in GC to achieve separation. Temperature and gas flow are two variables that may be controlled to vary RT. These are prerequisites for efficiency, selectivity, and problem resolution. Flame ionization detectors (FID) are still the gold standard for analyzing low amounts of complex volatile organic compounds (VOCs) in air and human metabolites because they provide more stable control than gas chromatography. One of the

things that GC is powerless to manage is flow rate. Its great sensitivity and capacity to forecast gasses that are unknown. Currently available micro-MS detectors with centimeter-scale components are unsuitable due to their complicated designs including massive analyzers, detectors, and ionization zones, and suffer from resolution and sensitivity issues due to restricted area for ion separation. Consequently, a variety of devices are utilized in place of conventional big MS or FID detectors, including micro/micro PIDs, chemical resistors, metal oxide semiconductors, capacitive detectors, and micro thermal conductivity detectors (μ -TCD). Numerous of these devices are available at the centimeter size, may be interfaced with μ -PC and μ -GC microfluidic devices, and are created utilizing MEMS technology. The present TD-GC-MS industry is meant to be replaced by this system. The procedure can be carried out in the following ways, notwithstanding variations in control operation. Observe the guidelines listed here. Three phases make up the analytical process: enrichment, TD, and separation/detection. First, low quantities of volatile organic compounds (VOCs) in μ -PC for the required amount of time during the pre-enrichment stage. Valves in the PC phase release VOCs to keep them out of the μ -GC system or detector. In addition, VOCs that were thermally desorbed in the TD phase after being transformed to greater concentrations utilizing μ -PC as a heat transfer medium. In order to transition between isothermal temperature management and a programmed mode that raises the temperature during separation/detection, a heater and RTD are utilized. High volumes of VOCs that have been thermally desorbed are introduced into the μ -GC system. The μ -GC system's electrical signal is controlled at different times using KEVID-19 Differential External Signals. [29, 30, 31]

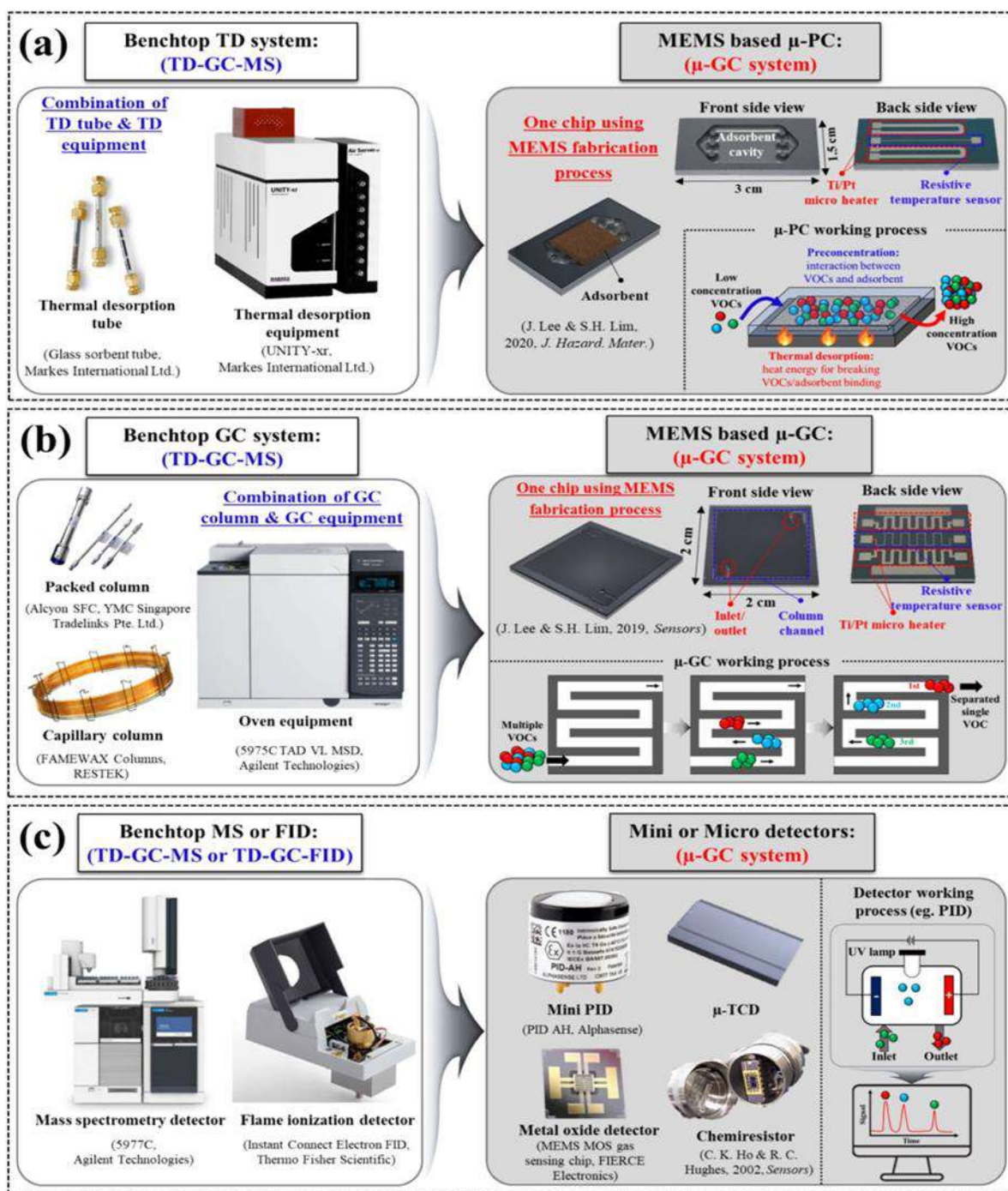


Figure 1 An overview of the TD-GC-MS and μ -GC systems' apparatus, systems, and consumables.

Hereunder: b GC system and GC detector; c MS/FID and micro/micro detector

The device described above (Figure 3) serves as the foundation for the functional analysis and integration of the μ -GC machine under investigation in this work. Generally speaking, Figures 5a and 5b depict a schematic of a typical μ -GC system, containing additional equipment like pumps and valves in addition to the major

parts. But in order to take into account new manufacturing methods, target volatile organic compounds, technology, and miniaturization, the integration or analysis process has undergone certain changes. To prevent band widening and fluid interfaces that might happen when integrating a device, the TCD is integrated into a

monolithic chip (Figure 3). 5c). When these two gadgets are combined, a good quantity of room is obtained. Furthermore, valves can be taken out. reducing the spatial confinement of temperature gradients with the use of porous polymers, enabling a straightforward design for the analytical method (Figure 3d). To assure water leakage reliability, avoid sample condensation at low temperatures, and give free space, connect the μ -PC and μ -GC systems (Figure 3e). The silicone FMB is made up of five membrane valves and three silicone plates. μ -O-rings are used to seal all of the connections. Because of its architecture, The smallest μ -GC system created to date is the tiny GC platform. These μ -GC systems increase efficiency, reproducibility, and dependability with less effort. For instance, PEMM-1 and PEMM-2 employ prefabricated goods coated in PDMS or belonging to the Carpark series (Figure 3f,g). Target VOCs may be monitored thanks to the pre-detection device in front of the μ -PC, which removes the adverse consequences of volatile

organic compounds. On the other hand, a two-dimensional (2D) GC was used in a portable GC \times GC system to monitor total volatile organic compounds (VOCs) (Figure 3h). Polar molecule separation and detection can be challenging in most μ -GC systems due to the use of nonpolar stationary phases; the combination of polar and nonpolar VOC targets is an exception. On the other hand, portable GC \times GC equipment transfers non-polar volatile organic compounds (VOCs) to the 1D column by opening and shutting valves during the 2D polar chromatography column, after first separating and capturing them using a one-dimensional (1D) non-polar column and PID. Applying μ -Deans key. The switch can detect the VOC signal secondary thanks to four more 2D polarity points and associated PIDs. By employing a reconstruction procedure for every PID data set, the The greatest number of systems ever built, 50 VOCs may be detected using a portable GC \times GC gadget. [32, 33, 34]

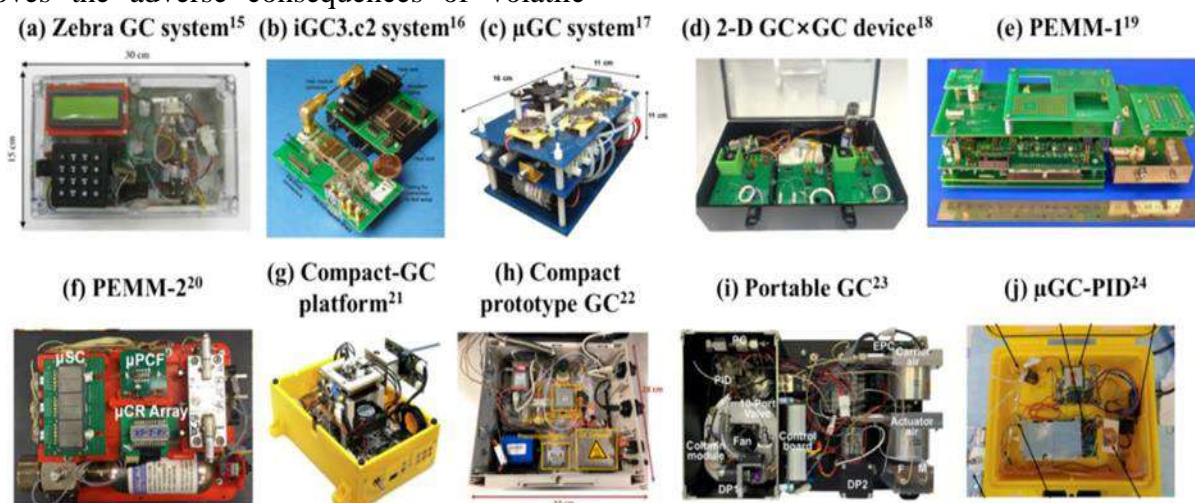


Figure 2 mages of GC systems with MEMS devices incorporated. a Zebra GC System [32,33,34]

Preconcentrator for micro gas (μ -PC)

A tiny precursor (PC) was initially created by Dave et al. to take the place of the thermal desorption (TD) procedure. 1969. Terry et al. introduced the first gas chromatography (GC) system based on silicon wafers. [35, 36, 37] The

project of creating a MEMS technology based on μ -PC that is appropriate for microfluidic systems started in 1979. Reversible gas adsorption and desorption phenomena are used by μ -PC to increase system sensitivity, and a variety of designs have been created based on the

microstructure and integrated adsorbent. Adsorption performance is significantly impacted by thermal desorption, which has prompted much study and design development. Cavity, film, and microstructure designs may be separated out of this design. [38,39, 40] Additionally, a key factor in influencing the effectiveness of adsorbent materials is their research and selection performance of μ -PC, including pre-treatment efficiency and adsorption capacity. The five categories of agent adsorbent materials include adsorbents using polymers, carbon, oxide, silicon, and metal-organic frameworks (MOFs). These categories are based on reverse physical adsorption/desorption. The performance of μ -PC is significantly influenced by the sorbent material, which is why a thorough analysis of each system and other μ -PC formulations is conducted. [41, 42, 43, 44, 45]

Micro -PC Design

Three different MEMS-based μ -PC design types are depicted in Figure 4. The first is called void creation, and it involves filling the void with an adsorbent. In the latter case, a thin layer of the adsorbent is applied to a flat surface or channel. The structure generated in the area coated or filled with adsorbent characterizes the third type of design, known as the microstructure design. The adsorbent material determines whether voids and membranes develop. Because of their large adsorbent mass and high adsorption capacity,

carbon-based adsorbents are widely employed in design; nevertheless, they also induce shock. Membrane systems with lower adsorption capacities but smaller losses employ polymer-based adsorbents. Because μ -PC is employed in microfluidic devices, the cross-sections of the entrance and output are big and the adsorbent filling area is extremely modest. Because of this design, which stops organic molecules from flowing over the boundary between the inlet and outflow, scientists have been working to better distribute the label throughout the whole adsorbent cross section. To account for the variation between fractions, a liquid filter was employed in a compact sample gas chromatograph (Figure 5a). By generating vertical microneedle patterns in the chamber to induce turbulence and enhance the interaction between adsorbents and volatile organic compounds (VOCs), the μ GC system enhances dispersion (Figure 5b). Low power consumption and maximum bandwidth are achieved by short range. This necessitates meticulous heating system design and construction, taking into account thermal insulation qualities, inadequate heat dissipation, and heat transfer. A μ -PC with a cantilever construction is seen in Figure 5c. minimizes heat generated by the iGC3.c2 system's thermal insulation. [45, 46]

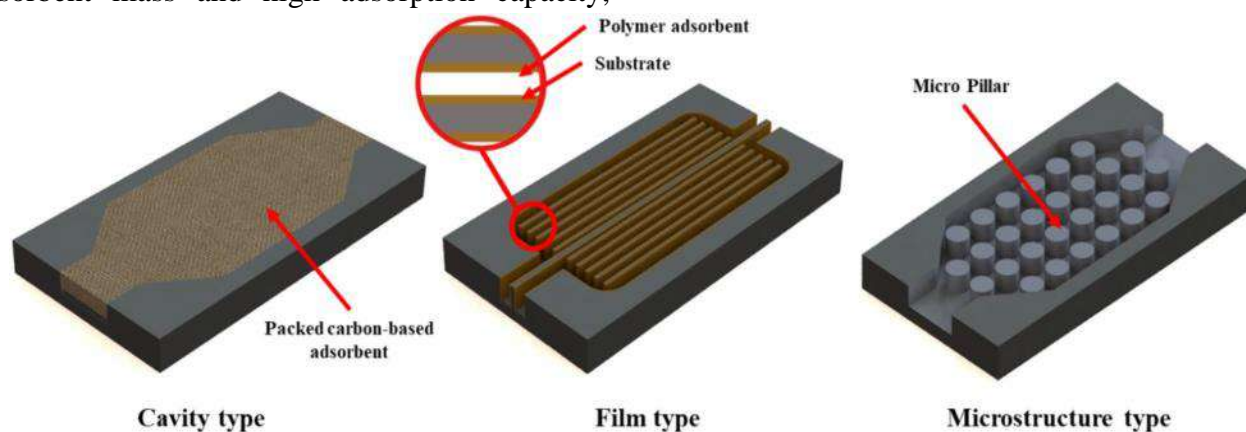


Figure 3 micro-PC design

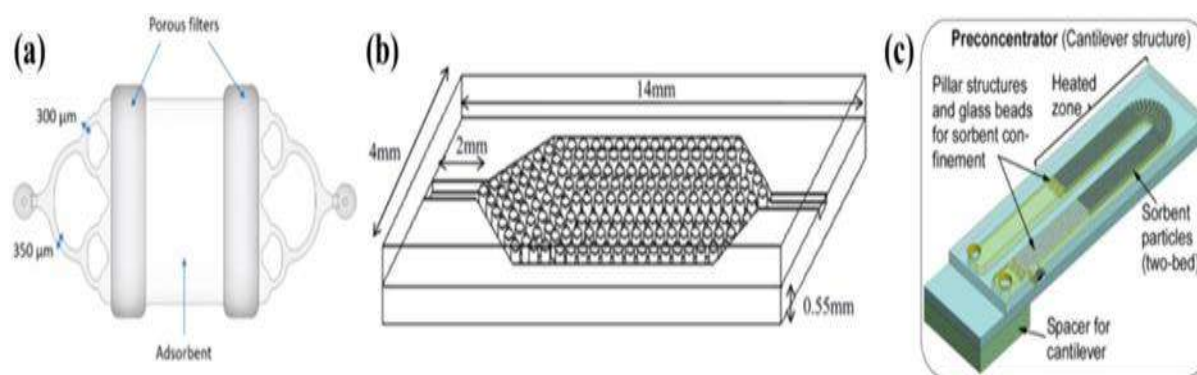


Figure 4 PCs that have been upgraded with certain features

Micro PC Adsorbent

A variety of μ -PC adsorbents, including as silicon, oxide, polymer, carbon, and MOF-based adsorbents, have been developed. Despite these advancements, Table 2 illustrates that the majority of adsorbents used today are carbon-based and include the Carboxpack, Carboxieve, and Carbograph series. It is Tenax TA covered with microstructured cavities specifically. This μ -PC produced a 973-fold greater concentration when it was applied for 2 minutes at a flow rate of 1 mL/min and desorbed for 12 seconds at 200 °C. A commercial MOF named Basolite C300 (HKUST-1) and a μ -PC fitted with a heat desorption box were employed. Carbon nanotube sponge adsorbents in glass tubes are also used in portable gas chromatographs. More significantly, the CNT sponge provided the smallest μ -GC analysis thermal desorption time with because of its great heat conductivity, only 3 seconds. PC adsorbent materials are constantly being developed in an effort to increase their efficiency, selectivity, and detection capabilities. [47, 48]

μ Gas Chromatography Column

Water may flow down μ -GC lines because they are created by etching micrometer-scale rectangular cross-section lines on the face of a centimeter-scale silicon wafer and bonding them with glass glue. For temperature regulation, RTDs (Resistance Temperature Detectors) and microheaters are often positioned in the rear. A stationary phase that interacts with the volatile

organic compounds (VOCs) and enables separation based on their contact is coated on the channel walls. The ideal separation measurement is less than the theoretical plate equivalent height (HETP).

Solution: Illustrate how two nearby vertices vary from one another.

Selectivity: The chromatography tube's capacity to distinguish between various compounds is referred to here.

Potential: Denotes how strongly the molecule interacts with the stationary phase.

Peak Asymmetry: Examine the peak's form; symmetric peaks are the best.

Channel Placement: The best possible arrangement of the plate's channels. The pipeline's efficiency is increased by the channel's form. Metal-organic frameworks (MOFs) are modeled using PDMS and their potential as novel stationary phases in gas chromatographic applications is discussed.

Detector

1. Photoionization Detector (PID)

PID focuses on the photoionization process by ionizing volatile organic compounds (VOCs) using ultraviolet (UV) light. It functions in the following ways:

Working principle: When photons from ultraviolet light strike electrons, they produce positive ions and ionize volatile organic compounds (VOCs). It ionizes ions, which produces electric current. Compact model GC,

portable GC, and small model (-PID) GC are examples of microfluidic devices that incorporate 2D GC.[49] High-energy photons, often in the vacuum ultraviolet (VUV) region, ionize molecules in a photoionization detector (PID) by splitting them into positively charged ions. High-energy UV photons strike the compounds as they reach the detector, and when they absorb the UV light, they ionize. Positive ions are formed and electrons are ejected as a result of this process. The detector's signal is an electric current produced by the ions. Component concentrations that are higher generate more ions, which enhance current flow. An amplified version of the current is shown on an ammeter or digital concentration readout. Since only a tiny portion of the analytes in air are first

ionized, the effect of certain ions' ability to recover electrons and return to their original molecule form is small. PID may therefore be employed in a variety of setups with other sensors and is regarded as non-destructive. lamp. PID is a broad-spectrum, non-selective measurement that may ionize an item with an ionization energy that is equivalent to or less than a photon of light. Most commercial light sources have photon energy limitations of about 8.4eV, 10.0eV, 10.6eV, and 11.7eV. Since organic chemicals (VOCs) often have ionization energies below 12.0 eV, large and minute particles of clean air can not interfere with their detection since their ionization energies are over 12.0 eV.

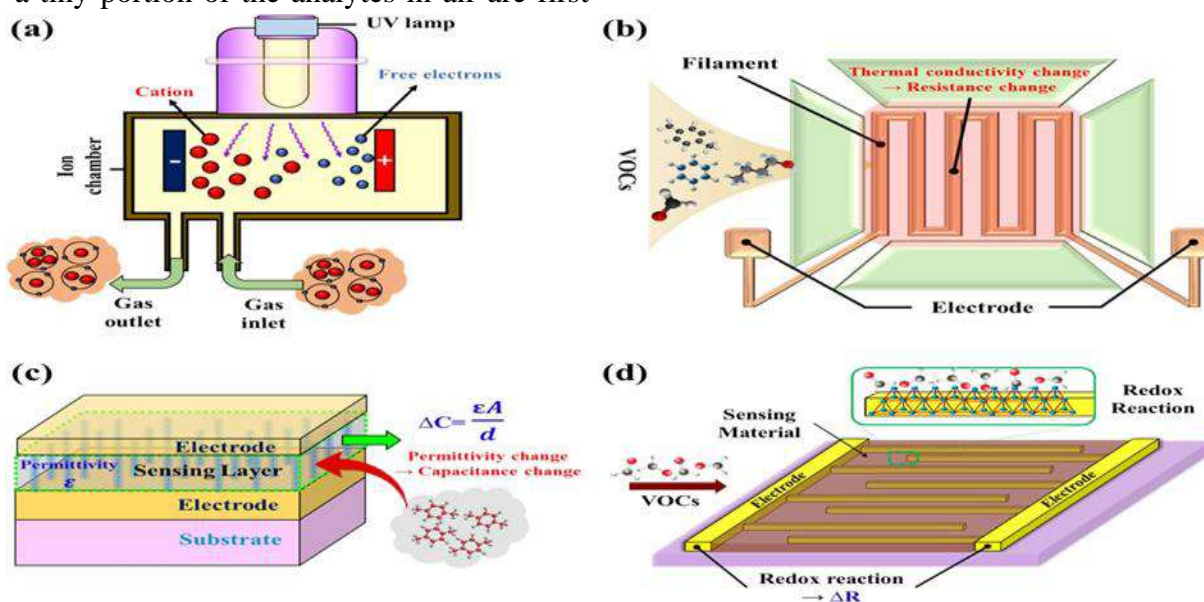


Figure 5 Configuration schematic for mini/micro-VOC detectors used in μ -GC systems, showing the sensing process. Photoionization detector (PID), micro-thermal conductivity sensing device (TCD), capacitive sensor, and chemical resistive detector (CRD) are the four types

2. Thermal Conductivity Detector (TCD)

By measuring a VOC's thermal conductivity against carrier gases like helium or hydrogen, TCD can identify them.

How it works: VOCs are eliminated from several material passes using a thermally insulated filament. for variations in heat conductivity to cause a change in the filament resistance. High temperature stability and strong heat conductivity are prerequisites for filament materials. [50,51]

3. Capacitive Detector

VOC is detected by a capacitive detector using continuous dielectric changes.

Operating principle: The electrode and the sensing layer (often a polymer dielectric or metal oxide) are part of the substrate. VOCs disrupt the sensing mechanism, altering the capacitance and dielectric constant as a result. VOC alternatives.[75]

4. Chemical Resistance Detector

The chemical resistance detector, when in contact with the sensing material, detects volatile organic compounds (VOCs) by changing its resistance.

Operating principle: Sensing material paper, which includes metal oxides like SnO₂ or ZnO, and volatile organic compounds (VOCs) Oxidation/reduction process, resistance changes. Every component is unique and may be utilized to meet a variety of objectives, ranging from high demand and quick reaction times to improved options and widespread usage in micro-volume GC.[76,77, 75]

Major problems that faces During micro gas chromatography:

Commercial: Although μ -GC systems have outstanding capabilities, there are issues with their widespread use:

Cost: high manufacturing costs as a result of base material production being done separately. In an effort to save costs and size, recent innovations have concentrated on combining μ -GC and μ -TCD into a single wafer.

Miniaturization: Increased miniaturization increases the range of applications possible:

Single die integration: Size and complexity are reduced when MEMS are connected to a single chip. This demand is lessened by innovations like motherboards made of liquid silicon. Performance and dependability in certain circumstances:

Test condition: restricted dependability data in an uncontrolled laboratory setting.

Selectivity: About the Need of Various VOCs for Selective Analysis:

Sensor Arrays: Potential Applications Sensor arrays are required in order to boost selectivity, even if VOC analysis is still difficult.

Stationary Phases: Investigate novel materials, like as MOFs, to enhance μ -GC system handling and interactions. Quality control: Examine interior spaces including houses, workplaces, and hospitals for potentially dangerous volatile organic compounds. Illness: μ -GC identification enabling prompt diagnosis in the clinic or at home.

CONCLUSION:

Over the course of over forty years, μ -GC systems have been developed, beginning with silicon wafer-based technology and progressing to encompass significant items like μ -PC, μ -GC lines, and captured objects. Through ongoing investigation and knowledge growth, this method aims to establish foundational focus, separation, and acquisition skills. Despite commercial attempts, μ -GC devices are still not widely used due to size and cost constraints, even though they are used for noninvasive diagnostics and air quality monitoring. There are still many significant obstacles to overcome, particularly in the creation of crucial instruments that can accurately and efficiently analyze every volatile organic molecule present in indoor and exhaled air. Materials like MOFs have the potential to address these issues by enhancing the performance of the μ -GC system and enabling single-phase integration to lower size, as well as cutting production costs. Progress in these materials will be critical to overcome the obstacles facing μ -GC systems' general commercialization.

REFERENCE

1. Nakaoka H, Todaka E, Seto H, Saito I, Hanazato M, Watanabe M, Mori C (2014) Correlating the symptoms of sick-building syndrome to indoor VOCs concentration levels and odour. *Indoor Built Environ* 23:804–813.
<https://doi.org/10.1177/1420326X13500975>



2. Sun Y, Hou J, Cheng R, Sheng Y, Zhang X, Sundell J (2019) Indoor air quality, ventilation and their associations with sick building syndrome in Chinese homes. *Energy Build* 197:112–119. <https://doi.org/10.1016/j.enbuild.2019.05.046>
3. Xu Y, Zhang Y (2003) An improved mass transfer based model for analyzing VOC emissions from building materials. *Atmos Environ* 37:2497–2505. [https://doi.org/10.1016/S1352-2310\(03\)00160-2](https://doi.org/10.1016/S1352-2310(03)00160-2)
4. Liu Z, Ye W, Little JC (2013) Predicting emissions of volatile and semivolatile organic compounds from building materials: a review. *Build Environ* 64:7–25. <https://doi.org/10.1016/j.buildenv.2013.02.012>
5. Boor BE, Järnström H, Novoselac A, Xu Y (2014) Infant exposure to emissions of volatile organic compounds from crib mattresses. *Environ Sci Technol* 48:3541–3549. <https://doi.org/10.1021/es405625q>
6. Maung TZ, Bishop JE, Holt E, Turner AM, Pfrang C (2022) Indoor air pollution and the health of vulnerable groups: a systematic review focused on particulate matter (PM), volatile organic compounds (VOCs) and their effects on children and people with pre-existing lung disease. *Int J Environ Res Public Health*. <https://doi.org/10.3390/ijerph19148752>
7. IARC (2021) Agents classified by the IARC monographs for cancer on WHO report. IARC. 2021:1–37. <https://monographs.iarc.who.int/agents-classified-by-the-iarc>. Accessed 16 Apr 2024.
8. Pathak AK, Swargiary K, Kongsawang N, Jitpratak P, Ajchareeyasontorn N, Udomkittivorakul J, Viphavakit C (2023) Recent advances in sensing materials targeting clinical volatile organic compound (VOC) biomarkers: a review. *Biosensors (Basel)*. <https://doi.org/10.3390/bios13010114>
9. R.E. Majors, *LC.GC North Am.* 17 (1999) S7.
10. R.E. Clement, P.W. Yang, C.J. Koester, *Anal. Chem.* 71 (1999) 257 R.
11. R.E. Clement, P.W. Yang, C.J. Koester, *Anal. Chem.* 73 (2001) 27
12. D.L. Fox, *Anal. Chem.* 71 (1999) 109 R.
13. S.D. Richardson, *Anal. Chem.* 73 (2001) 2719.
14. J. Dewulf, H. Van Langenhove, *Atmos. Environ* 31 (1997) 3291.
15. J. Dewulf, H. Van Langenhove, *Wat. Res.* 31 (1997) 1825.
16. USEP Agency (2017) Method 8260D: volatile organic compounds by gas chromatography/mass spectrometry. SW-864 Update VI. https://www.epa.gov/sites/default/files/2017-04/documents/method_8260d_update_vi_final_03-13-2017.pdf. Accessed 16 Apr 2024
17. Collin WR, Serrano G, Wright LK, Chang H, Nuñovero N, Zellers ET (2014) Microfabricated gas chromatograph for rapid, trace-level determinations of gas-phase explosive marker compounds. *Anal Chem* 86:655–663. <https://doi.org/10.1021/ac402961tDW>, Seon YS, Jang Y, Bang J, Oh JS, Jung KW (2020) A portable gas chromatograph for real-time monitoring of aromatic volatile organic compounds in air samples. *J Chromatogr A* 1625:461267. <https://doi.org/10.1016/j.chroma.2020.461267>
19. Wei-Hao Li M, Ghosh A, Venkatasubramanian A, Sharma R, Huang X, Fan X (2021) High-sensitivity micro-gas chromatograph-photoionization detector for trace vapor detection. *ACS Sens* 6:2348–

2355. <https://doi.org/10.1021/acssensors.1c00482>
20. Lu CJ, Steinecker WH, Tian WC, Oborny MC, Nichols JM, Agah M et al (2005) First-generation hybrid MEMS gas chromatograph. *Lab Chip* 5(10):1123–1131. <https://doi.org/10.1039/b508596a>
21. UNITY Document (n.d.) XR. <https://docs.unity3d.com/Manual/XR.html>. Accessed 16 Apr 2024.
22. Agilent (n.d.) 5977C GC/MSD. GC/MS Instruments. <https://www.agilent.com/en/product/gas-chromatography-mass-spectrometry-gc-ms/gc-ms-instruments/5977c-gc-msd>. Accessed 16 Apr 2024.
23. MARKES International (n.d.) Sorbent tubes - glass. <https://markes.com/samplingtechnologies/supplies-collection/sorbent-tubes-glass>. Accessed 16 Apr 2024.
24. Lee J, Lee J, Lim SH (2020) Micro gas preconcentrator using metal organic framework embedded metal foam for detection of low-concentration volatile organic compounds. *J Hazard Mater* 392:122145. <https://doi.org/10.1016/j.jhazmat.2020.122145> YMC (n.d.) Packed column. <http://www.ymc.sg/products/ymc-pack-c8/>. Accessed 16 Apr 2024.
25. RESTEK (n.d.) Capillary column. <https://www.restek.com/global/en/p/11140>. Accessed 16 Apr 2024 Agilent Technologies (2012) Agilent 5975 Series MSD: Operation Manual <https://www.agilent.com/cs/library/usermanuals/public/G3170-90036.pdf>. Accessed 16 Apr 2024.
26. Lee J, Lim SH (2019) Development of Open-tubular-type micro gas chromatography column with bump structures. *Sensors (Basel)*. <https://doi.org/10.3390/s19173706>
27. ThermoFisher Scientific (n.d.) iConnect™ flame ionization detector (FID) for TRACE™ 1300 and 1600 series GC. <https://www.thermofisher.com/order/catalog/product/19070001?SID=srch-hj-19070001>. Accessed 16 Apr 2024.
28. Alphasense AMETEK (n.d.) PID-AH2 photo ionisation detector. https://ametekcdn.azureedge.net/mediafiles/project/oneweb/oneweb/alpha_sense/products/datasheets/alphasense_pid-ah2_datasheet_en_1.pdf?revision:bf5b3e8a-c6a3-4608-ae2e-b3b91032485b. Accessed 16 Apr 2024.
29. FIERCE Electronics (2018) Metal oxide gas sensing material and MEMS process. <https://www.fierceelectronics.com/components/metal-oxide-gas-sensing-material-and-mems-process>. Accessed 16 Apr 2024.
30. Ho CK, Hughes RC (2002) In-situ chemiresistor sensor package for real-time detection of volatile organic compounds in soil and groundwater. *Sensors* 2:23–34. <https://doi.org/10.3390/s20100023>
31. Lee J, Zhou M, Zhu H, Nidetz R, Kurabayashi K, Fan X (2016) Fully automated portable comprehensive 2-dimensional gas chromatography device. *Anal Chem* 88:10266–10274. <https://doi.org/10.1021/acs.analchem.6b03000>
32. Wang J, Bryant-Genevier J, Nuñovero N, Zhang C, Kraay B, Zhan C, Scholten K, Nidetz R, Buggaveeti S, Zellers ET (2018) Compact prototype microfabricated gas chromatographic analyzer for autonomous determinations of VOC mixtures at typical workplace concentrations. *Microsyst Nanoeng.* <https://doi.org/10.1038/micronano.2017.101>

34. Wang J, Nuño N, Nidetz R, Peterson SJ, Brookover BM, Steinecker WH, Zellers ET (2019) Belt-mounted micro-gas-chromatograph prototype for determining personal exposures to volatile-organic-compound mixture components. *Anal Chem* 91:4747–4754. <https://doi.org/10.1021/acs.analchem.9b00263>
35. Dave SB (1969) A comparison of the chromatographic properties of porous polymers. *J Chromatographic Sci* 7:389–399. <https://doi.org/10.1093/chromsci/7.7.389>
36. Terry SC, Jerman JH, Angell JB (1979) A gas chromatographic air analyzer fabricated on a silicon wafer. *IEEE Trans Electron Devices* 26:1880–1886. <https://doi.org/10.1109/T-ED.1979.19791>
37. McCartney MM, Zrodnikov Y, Fung AG, LeVasseur MK, Pedersen JM, Zamuruyev KO, Aksenov AA, Kenyon NJ, Davis CE (2017) An easy to manufacture micro gas preconcentrator for chemical sensing applications. *ACS Sens* 2:1167–1174. <https://doi.org/10.1021/acssensors.7b00289>
38. Bryant-Genevier J, Zellers ET (2015) Toward a microfabricated preconcentrator-focuser for a wearable micro-scale gas chromatograph. *J Chromatogr A* 1422:299–309. <https://doi.org/10.1016/j.chroma.2015.10.045>
39. Stolarczyk A, Jarosz T (2022) Micropreconcentrators: recent progress in designs and applications. *Sensors (Basel)*. <https://doi.org/10.3390/s22041327>
40. Lahlou H, Vilanova X, Correig X (2013) Gas phase micro-preconcentrators for benzene monitoring: a review. *Sens Actuators, B Chem* 176:198–210. <https://doi.org/10.1016/j.snb.2012.10.004>
41. Wang Y, Chen Z, Chen Q, Tian E, Han N, Mo J (2024) Preconcentrating sensor systems toward indoor low-concentration VOC detection by goal-oriented, sequential, inverse design strategy. *Build Environ* 254:111372. <https://doi.org/10.1016/j.buildenv.2024.111372>
42. Lara-Ibeas I, Rodríguez Cuevas A, Le Calvé S. Recent developments and trends in miniaturized gas preconcentrators for portable gas chromatography systems: a review. *Sensors Actuators B Chem*. 346:130449. <https://doi.org/10.1016/j.snb.2021.130449>.
43. Serrano G, Sukaew T, Zellers ET (2013) Hybrid preconcentrator/focuser module for determinations of explosive marker compounds with a micro-scale gas chromatograph. *J Chromatogr A* 1279:76–85. <https://doi.org/10.1016/j.chroma.2013.01.009>
44. Woellner M, Hausdorf S, Klein N, Mueller P, Smith MW, Kaskel S (2018) Adsorption and detection of hazardous trace gases by metal-organic frameworks. *Adv Mater* 30:e1704679. <https://doi.org/10.1002/adma.201704679>
45. Wong MY, Cheng WR, Liu MH, Tian WC, Lu CJ (2012) A preconcentrator chip employing mu-SPME array coated with in-situ-synthesized carbon adsorbent film for VOCs analysis. *Talanta* 101:307–313. <https://doi.org/10.1016/j.talanta.2012.09.031>
46. Ruiz AM, Gràcia I, Sabaté N, Ivanov P, Sánchez A, Duch M, Gerbolés M, Moreno A, Cané C (2007) Membrane-suspended microgrid as a gas preconcentrator for chromatographic applications. *Sens Actuators A* 135:192–196. <https://doi.org/10.1016/j.sna.2006.07.005>
47. Chowdhury AR, Lee T, Day C, Hutter T (2022) A review of preconcentrator materials, flow regimes and detection technologies for gas adsorption and sensing. *Adv Mater*

Interfaces.

<https://doi.org/10.1002/admi.20220632>

48. Alfeeli B, Jain V, Johnson RK, Beyer FL, Heflin JR, Agah M (2011) Characterization of poly(2,6-diphenyl-p-phenylene oxide) films as adsorbent for microfabricated preconcentrators. *Microchem J* 98:240–245. <https://doi.org/10.1016/j.microc.2011.02.006>
49. Coelho Rezende G, Le Calvé S, Brandner JJ, Newport D (2019) Micro photoionization detectors. *Sens Actuators B* 287:86–94. <https://doi.org/10.1016/j.snb.2019.01.072>
50. Sun JH, Cui DF, Chen X, Zhang LL, Cai HY, Li H (2013) A micro gas chromatography column with a micro thermal conductivity detector for volatile organic compound analysis. *Rev Sci Instrum* 84:025001. <https://doi.org/10.1063/1.4789526>
51. Cruz D, Chang J, Showalter S, Gelbard F, Manginell R, Blain M (2007) Microfabricated thermal conductivity detector for the micro-ChemLab™. *Sens Actuators B* 121:414–422. <https://doi.org/10.1016/j.snb.2006.04.107>
52. Baharuddin AA, Ang BC, Haseeb ASMA, Wong YC, Wong YH (2019) Advances in chemiresistive sensors for acetone gas detection. *Mater Sci Semicond Process.* <https://doi.org/10.1016/j.mssp.2019.104616>
53. Franco MA, Conti PP, Andre RS, Correa DS (2022) A review on chemiresistive ZnO gas sensors. *Sens Actuators Rep.* <https://doi.org/10.1016/j.snr.2022.100100>
54. Jo YM, Jo YK, Lee JH, Jang HW, Hwang IS, Yoo DJ (2023) MOF-based chemiresistive gas sensors: toward new functionalities. *Adv Mater* 35:e2206842. <https://doi.org/10.1002/adma.202206842>

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