

REVIEW

Miniature Mass Spectrometry for VOCs Analysis: Recent Developments in Instrumentation and Applications

Junhe Cao | Ting Jiang  | Wei Xu 

School of Medical Technology, Beijing Institute of Technology, Beijing, China

Correspondence: Ting Jiang (6120250051@bit.edu.cn) | Wei Xu (weixu@bit.edu.cn)

Received: 24 April 2023 | Revised: 22 May 2023 | Accepted: 23 May 2023

Keywords: clinical application | food authentication | ion sources | miniature mass spectrometers | volatile organic compounds (VOCs)

ABSTRACT

Rationale: Volatile organic compounds (VOCs) are critical indicators of environmental and biological processes and their analysis is essential for various applications, including environmental monitoring, food safety and clinical diagnostics.

Methods: Traditional mass spectrometry (MS) techniques, such as gas chromatography–mass spectrometry (GC–MS), are widely regarded as gold standards for VOCs detection. However, their lack of portability and limited real-time analytical capabilities hinder their widespread use in on-site and rapid detection applications. Miniature mass spectrometry has emerged as a promising solution by integrating compact instrumentation with innovative ionization techniques, including ultraviolet-based, plasma-based and electron ionization methods.

Results: Recent advancements in mini-MS have focused on enhancing portability, sensitivity and adaptability to complex sample matrices. These developments include the integration of novel sampling interfaces, such as membrane inlet and atmospheric pressure interfaces. Despite these advances, challenges remain in optimizing sensitivity, selectivity and compatibility with real-world samples.

Conclusions: This review synthesizes recent progress in the field of miniature mass spectrometry for VOCs analysis, emphasizing key technological innovations, such as ionization and sampling improvements, portable platform development. The review also explores mini-MS applications in food authenticity, clinical diagnostics, highlighting the growing potential of these technologies to revolutionize on-site, real-time VOCs detection across diverse fields.

1 | Introduction

Volatile organic compounds (VOCs) are key components of biomarkers [1] and environmental pollutants that impact air quality [2], human health [3] and industrial processes [4]. For trace VOC analysis, a variety of analytical techniques have been developed, including gas chromatography (GC), ion mobility spectrometry (IMS), electronic nose (E-nose) and Raman spectroscopy [4–8]. Among them, GC–MS remains one of the most recognized method due to its sensitivity and accuracy. Despite the excellent performance of lab-scale GC–MS, its limited portability, lack of real-time analysis capabilities and poor adaptability to complex matrices restrict its application in fields such as environmental

monitoring, food safety and clinical diagnostics, where rapid, on-site detection is essential.

In recent years, the development of mini-MS has overcome these challenges by integrating novel ionization techniques and compact instrumentation. Significant efforts have been dedicated to the miniaturization of MS for VOC analysis [9], focusing on sampling interfaces, ion sources, mass analyzers and integrated platforms to enhance portability, real-time detection and adaptability in diverse applications. The development of sampling interfaces for miniature mass spectrometers began with membrane inlet (MI) systems, which commercialized by various companies and are widely used for in situ

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Table of Contents Recent Developments In Mass Spectromet 6

1. Understanding the eBook Recent Developments In Mass Spectromet 6
 - The Rise of Digital Reading Recent Developments In Mass Spectromet 6
 - Advantages of eBooks Over Traditional Books
2. Identifying Recent Developments In Mass Spectromet 6
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Recent Developments In Mass Spectromet 6
 - User-Friendly Interface
4. Exploring eBook Recommendations from Recent Developments In Mass Spectromet 6

- Personalized Recommendations
- Recent Developments In Mass Spectrometry 6 User Reviews and Ratings
- Recent Developments In Mass Spectrometry 6 and Bestseller Lists
- 5. Accessing Recent Developments In Mass Spectrometry 6 Free and Paid eBooks
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 - Recent Developments In Mass Spectrometry 6 eBook Subscription Services
 - Recent Developments In Mass Spectrometry 6 Budget-Friendly Options
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 - ePub, PDF, MOBI, and More
 - Recent Developments In Mass Spectrometry 6 Compatibility with Devices
 - Recent Developments In Mass Spectrometry 6 Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Recent Developments In Mass Spectrometry 6
 - Highlighting and Note-Taking Recent Developments In Mass Spectrometry 6
 - Interactive Elements Recent Developments In Mass Spectrometry 6
- 8. Staying Engaged with Recent Developments In Mass Spectrometry 6
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Recent Developments In Mass Spectrometry 6
- 9. Balancing eBooks and Physical Books Recent Developments In Mass Spectrometry 6
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Recent Developments In Mass Spectrometry 6
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Recent Developments In Mass Spectrometry 6
 - Setting Reading Goals Recent Developments In Mass Spectrometry 6
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Recent Developments In Mass Spectrometry 6

- Fact-Checking eBook Content of Recent Developments In Mass Spectromet 6
- Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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