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REVIEW

Imaging liquids using microfluidic cells

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Abstract Chemistry occurring in the liquid and liquid surface is important in many applications. Chemical imaging of liquids using vacuum-based analytical techniques is challenging due to the difficulty in working with liquids with high volatility. Recent development in microfluidics enabled and increased our capabilities to study liquid in situ using sensitive techniques such as electron microscopy and spectroscopy. Due to its small size, low cost, and flexibility in design, liquid cells based on microfluidics have been increasingly used in studying and imaging complex phenomena involving liquids. This paper presents a review of microfluidic cells that were developed to adapt to electron microscopes and various spectrometers for in situ chemical analysis and imaging of liquids. The following topics will be covered, including cell designs, fabrication techniques, unique technical features for vacuum compatible cells (e.g., detection windows, device materials), and imaging with electron microscopy and spectroscopy. Challenges are summarized and recommendations for future development priority are proposed.

Keywords Microfluidic cell · Fabrication · Liquid · Vacuum compatible · In situ · Imaging

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1 Introduction

Due to the increasing need of microfluidic device in imaging liquids in real-time using electron microscopy and spectroscopy techniques, it is imperative we understand the fundamental design, fabrication, and applications of microfluidic cells. This review aims to provide an introduction of the technical approaches commonly used to develop one-of-a-kind flow cells for unique scientific research since the 1990s. The review will first describe liquid cell designs used in various studies, then dive into more details in device fabrications. Emphasis will be placed on applications of microfluidic-based static and flow cells in studying complicated fundamental physical and chemical phenomena using in situ electron microscopy and spectroscopy. Present technical challenges to obtain multimodality (i.e., one sample analyzed by more than one analytical technique) will be discussed. Recommendations for a path forward will be proposed in the end.

It is a technical challenge to study liquids using vacuum techniques. The liquid jet was pioneered for electron and X-ray analysis of liquids. It directs a water jet (5–50 μm diameter) into a cryopumped vacuum chamber and requires a specialized system (Faubel et al. 1988). A well-known problem is extreme supercooling and freezing due to water evaporation from the jet. In addition to gas–liquid study, the liquid jet has been used in liquid–solid study using a specially designed ultra-high vacuum (UHV) chamber (Gardin and Somorjai 1993). Other existing alternative approaches include the environmental scanning electron microscopy (ESEM) (Danilatos 1981), synchrotron-based X-ray photoelectron spectroscopy (XPS) (Ghosal et al. 2005; Nebel et al. 2006; Pantfoerder et al. 2005), transmission electron microscopy (TEM) (Furuya et al. 2008), and "wet-scanning transmission electron microscopy (STEM)" (Bogner et al. 2007).