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Abstract

MEMS Valves with Molecular Flow Regime Orifices †

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Abstract: In this work, a novel, silicon-based micro-electromechanical valve that includes a submicrometric orifice and can operate at pressure gradients of 1 bar was used to enhance sampling for gas chromatograph mass spectrometers. The valve is based on a membrane-in-membrane design and operates with thermomechanical actuation. It includes a pin to enable self-cleaning. Prototypes were fabricated and preliminary testing was performed.

Keywords: MEMS; nanofluidics; mass spectrometer; silicon nitride; HF vapor

1. Introduction

Great improvement in gas chromatograph mass spectrometers (GC-MSs) is possible using nanometer-scale orifices [1] as sampling points and smart gas interfaces towards atmospheric pressure. At high pressure gradients, orifices with diameters of about 100 nm operate under a molecular flow regime (MFR) [2]. A flow through conductance in an MFR does not give origin to gas collective motions, preventing condensation, chemical reactions and clogging [3]. Such inlet diameters enable gas flows in the range from 10^{-5} to 10^{-7} mbar L/s that guarantee the same concentrations of the external gases into the ionization chamber [4,5]. Such devices will be exposed to a 1 bar pressure gradient, with the sensing chamber on one side (in vacuum) and the analyte-containing ambient (at atmospheric pressure) on the other. A membrane with submicron orifices capable of consistently withstanding 1 bar pressure gradient was developed by the authors using a novel membrane-in-membrane structure [6].

We hereby report the development of an analogous nanoscale orifice membrane with a thermomechanically actuated valve to enable its operation and self-cleaning.

2. Materials and Methods

The device structure (Figure 1) was modified in order to include the thermomechanical valve component, but the same membrane-in-membrane approach was adopted. An inductively coupled, plasma-enhanced vapor deposition (ICP-CVD) silicon nitride film was developed for this device, demonstrating low residual stress after annealing. Based on the simulation results, a batch of prototype devices was designed and microfabricated on 6-inch SEMI standard silicon wafers. An example of the fabricated devices is reported in Figure 2.

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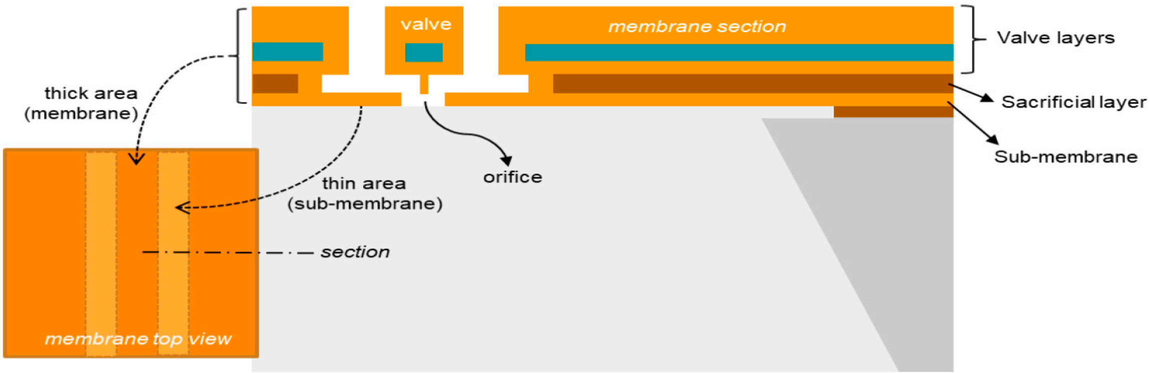

Figure 1. Membrane and bridge valve section.

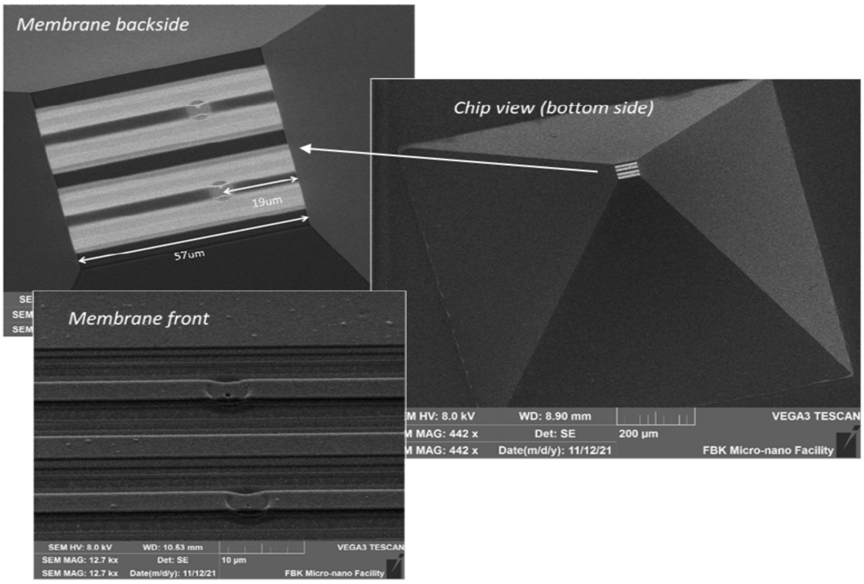

Figure 2. SEM image of the fabricated membrane with a bridge valve.

3. Results

The first fabrication batch was successfully completed. The devices were bonded on copper circular substrates having a passing hole. These substrates provide a mounting support in the vacuum system, and are equipped with a flat cable connection to the MEMS device. Thermoelectric valve actuation was demonstrated at ambient pressure, and resistance towards the pressure gradient was demonstrated under a full vacuum by mounting the device in a quadrupole mass filter spectrometer system that operated at a background pressure ranging from 10^{-9} to 10^{-10} mbar.

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