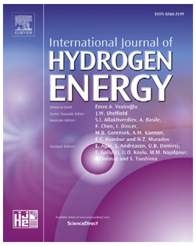
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–13

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he



Calibration of low-pressure MEMS gas sensor for detection of hydrogen gas

M. Barzegar Gerdroodbary [a,*], A. Anazadehsayed [b], A. Hassanvand [c], R. Moradi [d]

[a] Department of Mechanical Engineering, Babol University of Technology, Babol, Iran
[b] Swinburne University of Technology, Hawthorn, Victoria, 3122, Australia
[c] Department of Polymer Engineering, Faculty of Engineering, Lorestan University, Khorramabad, Iran
[d] Department of Chemical Engineering, School of Engineering & Applied Science, Khazar University, Baku, Azerbaijan

ARTICLE INFO

Article history:
Received 14 April 2017
Received in revised form
10 November 2017
Accepted 11 November 2017
Available online xxx

Keywords:
Knudsen force
DSMC
Rarefied gas
Low-pressure gas actuators
MEMS

ABSTRACT

Detection of hydrogen by sensors are significant for improvement and safe usage of hydrogen gas as an energy source. In this paper, the application of the MEMS gas sensor for detection of hydrogen gas is numerically studied to develop the application of this device in different industrial applications. The flow feature and force generation mechanism inside a rectangular enclosure with heat and cold arms as the non-isothermal walls are inclusively discussed. In this study, the pressure of hydrogen is varied from 62 to 1500 pa correspond to Knudsen number from 0.1 to 4.5 to investigate all characteristics of the thermal-driven force inside the MEMS sensor. In order to simulate a rarefied gas inside the micro gas detector, Boltzmann equations are applied to obtain high precision results. To solve these equations, Direct Simulation Monte Carlo (DSMC) approach is used as a robust method for the non-equilibrium flow field. The effects of length, thickness and temperature of arms are comprehensively investigated in different ambient pressures. In addition, the effect of various hydrogen concentrations on the Knudsen force is studied. Our findings show that maximum Knudsen force occurs at $P = 387$ pressure and intensifies when the length of the arms is increased from 50 μm to 150 μm. In addition, the obtained results demonstrate that the generated force is highly sensitive to hydrogen gas species and this enables device for detection of hydrogen gas.

Introduction

Currently, various sensing technologies are available to detect hydrogen due to its numerous applications in industries. Various researchers [1,2] comprehensively studied different types of hydrogen sensors according to characteristics and technologies such as mechanical properties, catalytic combustion and electrochemical properties. In addition, the analysis of the market shows that there are numerous highly qualified hydrogen sensors [2–4]. Since the current gas sensors such as gas Chromatographs, mass spectrometers or

---

* Corresponding author.
E-mail address: mbarzegarg@yahoo.com (M. Barzegar Gerdroodbary).

https://doi.org/10.1016/j.ijhydene.2017.11.087

Please cite this article in press as: Barzegar Gerdroodbary M, et al., Calibration of low-pressure MEMS gas sensor for detection of hydrogen gas, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.11.087

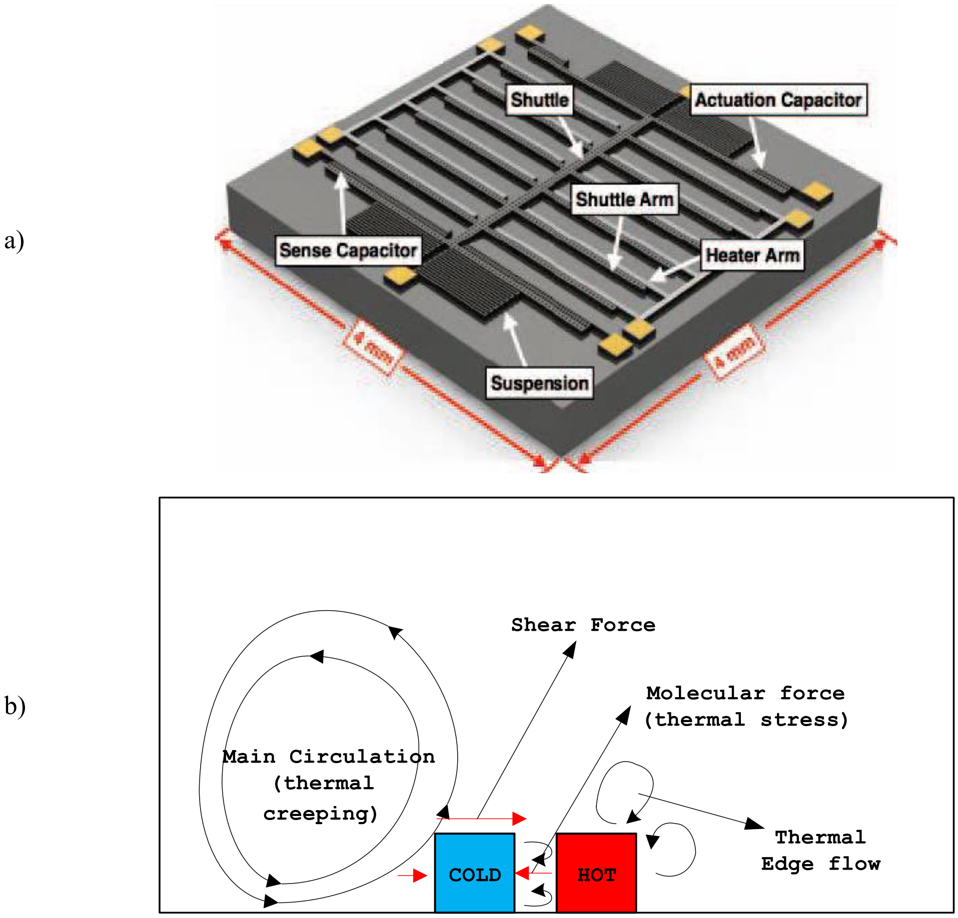


Fig. 1 – a) MIKRA device [11] b) Schematic of flow inside the MEMS sensor.

specific ionization gas pressure sensors are spacious, complicated and expensive, scholars and researchers have focused on the MEMS gas sensor to reach more efficient and simple method [5,6]. On the other side, the wide applications of the fuel cell intensify a need for a device to monitor and check the environment of the fuel cells for traces of leaked hydrogen. One of the relative new approaches for either the detection of the gas or measurement of pressure value is a radiometric force. Since the characteristics of the gas in the low pressure is proportional to the specification of the molecules, this approach is a significant method for the measurement and evaluation of different gases.

The famous radiometer of Sir William Crookes was one of the significant devices that has taken the attention of significant scientists such as Maxwell [7], Reynolds [8], and Einstein [9]. This radiometer works upon the inconsistency of temperature in rarefied domain. Over long time through extensive examinations and investigations (refer to a comprehensive review by Ketsdever et al. [10]), they found that temperature homogeneities lead to thermal stresses in rarefied gases and produce bulk fluid flows that could exert forces on immersed structures [11]. They also found that the main mechanism of force production is related to physical and environmental condition such as the ambient gas composition, pressure, in addition to the thermal gradient magnitude and direction. Since this force is induced in rarefied gas with high Knudsen numbers, scientists named this force as Knudsen thermal force.

Scientist found that Knudsen force is accessible in rarefied gas when the size of the domain is reduced in the micro scale. Passian et al. [12,13] described the potential of utilizing the Knudsen force at the microscale for the first time. They presented a microcantilever that was heated by a chopped laser and capacity of force is determined by out-of-plane deflection at different pressures. Lereu et al. [14] focused on effect of thermal variations on the Knudsen forces in the transitional regime. They presented the thermal dependence of these

Table 1 – Numerical specification.

Parameter	Unit	Value
Cell size	μm	4
Number of particles in each cell	–	20
Time step	s	1×10^{-8}
The number of time step	–	$3 \times 10^{+6}$
Total number of grid	–	9910

Please cite this article in press as: Barzegar Gerdroodbary M, et al., Calibration of low-pressure MEMS gas sensor for detection of hydrogen gas, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.11.087