ABSTRACT

Micro/nano satellites for future space missions require miniature propulsion systems for precise and accurate control of space craft. The microfabrication technology of MEMS (microelectromechanical systems) has been successfully employed to batch-fabricate micro-propulsion systems or micro-thrusters capable of producing extremely small thrusts in the range of micro-Newtons to mili-Newtons.

The present study aims to design and fabricate MEMS microthruster of two different types Vaporizing Liquid Microthruster (VLM) and catalyst based chemical microthruster exploiting a common structural configuration. The thruster was designed to achieve high thrust force and specific impulse with minimum electrical power for continuous operation with variable micro-order thrust. Silicon MEMS VLM was realized with converging-diverging in-plane exit nozzle and two p-diffused microheaters located at top and bottom surface of the device. The boron diffused microheaters of meanderline configuration in silicon substrate has been designed and its finite element based electrothermal modeling was employed to predict the heater characteristics. Structural configuration of VLM was designed using simple analytical equations to achieve maximum thrust force by controlling the inlet propellant flow and heater power of VLM in an efficient way. In addition, a 3D model using a computational fluid dynamics technique was simulated to investigate its aerodynamic behavior. The fabricated VLM is capable to produce 1 mN thrust using maximum heater power of 3.6 W at a water flow rate of 2.04 mg s^{-1}. A detailed thrust force measurement was carried out with the variation of input heater power for different mass flow conditions and exit to throat area ratio of the exit nozzle, and the results were interpreted with the theoretical model. The model gives considerable physical insight in the operation of the VLM.

The VLM study has been extended to demonstrate the feasibility of chemically synthesized MnO_2 nanowire catalyst embedded silicon MEMS H_2O_2 monopropellant microthruster. Due to exothermic reaction process, sustenance of thrust generation does not require any heating of propellant thus minimizing electrical power requirement. Nozzle configuration and catalyst bed were designed using analytical equations to achieve complete decomposition of H_2O_2 and maximum thrust force by controlling the propellant flow. Simulation of hydrogen peroxide decomposition process was carried out to evaluate the thermo-chemical characteristics. The MnO_2 nanowire has been obtained using a low cost synthesis process. Detailed thrust measurements reveal that maximum 1.08 mN thrust force and specific impulse of 180 s was achieved using 50% concentrated H_2O_2 of flow rate 1.25 mg s^{-1} with 2.2 W powers for preheating the catalyst bed.

Exploiting the unique characteristics of carbon nanotubes and nanofibers some effort was given to realize silicon MEMS based chemical monopropellant microthruster by integrating iridium supported on carbon nanotubes (CNTs) in the thruster chamber to act as catalyst required for propellant decomposition process. The device has been realized by using commercially available CNTs and experimental results show that the thrust force in the range of 0.25 –1.065 mN could be produced by varying 50% H_2O_2 mass flow rate of 0.2–1.50 ms s^{-1}.

Compatibility study of silicon and its different multilayer structures with hydrazine for its use as MEMS thruster have been carried out. Thin film multilayer structure of different derivatives of silicon was deposited by r.f. sputtering technique and treated with hydrazine for various ambient conditions. Subsequently the chemically treated samples were characterized for structural, chemical and electrical properties. It was observed that surface morphology and chemical bonding of silicon modified during the chemical treatment. Surface wettability study through contact angle measurement and electrical current density measurement of the samples were carried out to evaluate the passivation characteristics of multilayer structures. Based on the experiment results, it is observed that the $Si/SiO_2/Si_3N_4$ stack layer is the most promising passivation layer for hydrazine-based silicon MEMS microthruster.

Superior performance of VLM thruster in terms of thrust and specific impulse generation as compared to the available literature reports by incorporating two heater configuration and synchronous propellant flow with input power and first time reported MnO_2 nanowires and CNTs catalyst based silicon MEMS chemical monopropellant thruster are the major achievements in the present dissertation.

***Keywords*: MEMS, Micropropulsion, Microthruster, CFD, hydrogen peroxide, MnO_2 nanowire, CNTs, catalyst, hydrazine, thin films, thrust.**