Fabrication Technology of Quartz Glass Microresonator Using Sacrificial Metal Support Structure

著者	Khan Muhammad Jehanzeb
学位授与機関	Tohoku University
学位授与番号	11301甲第19491号
URL	http://hdl.handle.net/10097/00134277

	ハンムハマドジェハンゼブ
氏　　　　　名	Khan Muhammad Jehanzeb
研究科，専攻の名称	東北大学大学院工学研究科（博士課程）ロボティクス専攻
学 位 論 文 題 目	Fabrication Technology of Quartz Glass Microresonator Using Sacrificial Metal Support Structure (犠牲金属支持構造を用いた石英ガラスマイクロ共振子の作製技術)
論 文 審 査 委 員	主査　東北大学教授　田中秀治　東北大学教授　羽根一博 東北大学教授　小野崇人　東北大学准教授　塚本貴城

論文内容要約

This research study is to design and fabricate a new technology by using quartz glass which can be applicable for high factor micro-resonators. These technologies were designed such that they hold a possible potential for batch fabrication a micro-electro-mechanical-systems (MEMS) - complimentary metal-oxide semiconductor (CMOS) integration.

In the chapter 1, the brief literature review is discussed such that currently used gyroscopes and their shortcomings can highlighted. Later types of micro-resonators are discussed; these resonators mostly rely on SOI MEMS process. T micro-resonator degradation mechanisms such anchor-loss, thermoelastic dissipation (TED), gas damping and surface loss are discussed. In the final section the organization of thesis is discussed.

In chapter 2, the design of the micro-resonator and state-of-the-art SOI MEMS process for electromagnetic resonators is presented. First the design was optimized by FEM analysis to minimize anchor-loss. The reaction force cancellation in the centrally anchored structure was confirmed by FEM analysis. In the second step reference SOI MEMS process was developed. The device was successfully actuated in n = 2 wineglass modes at resonant frequency 10.5 kHz close to the simulated design value. The phase and amplitude provided almost ideal mode matching. The Q-factor in both modes was ~20. In the second stage of FEM analysis TED related study was conducted. The material properties of both materials were inserted to study the TED effect on the Q-factor. Quartz glass had ~2.3 million Q_{TED} and Si had only ~29000. Based on this result, ring resonator was fabricated from quartz glass in the later part of the study.

In the second phase of the study, first novel fabrication technology quartz glass-on-metal support (QOM) MEMS process was developed, similar to silicon-on-insulator (SOI) MEMS process. In this process quartz glass substrates were used as device and handle layer and they were bonded by gold-gold (Au-Au) thermocompression bonding. Quartz glass was used due to low coefficient of thermal expansion (CTE) 5.6 x 10^{-7} [/K] in place of Si having CTE 2.6 x 10^{-6} [/K]. The fabricated quartz glass cantilevers were mechanically supported by Au posts. The mechanical supporting structures consist of anchor structures and sacrificial supporting structures. The anchor structure remains to support the fabricated cantilevers during operation while the sacrificial supporting structures are removed during the release process of the cantilevers. The sacrificial supporting structures were employed to mechanically support the fragile cantilever structure during the whole fabrication process.

The supporting structures also played a role to dissipate the generated heat during the plasma process and keep the device layer temperature low. Using the proposed method, micromachined cantilevers were successfully fabricated on the quartz glass substrate. These cantilevers were evaluated with external actuation. The fabricated cantilevers were strictly in agreement with linearity feature e.g. resonant frequency increased linearly by changing design parameters and also matched the FEM modal shapes.

In the third phase of the study, QOM technology was improved for making it compatible with electrically driven devices. Later state-of-the-art electromagnetic ring resonator was fabricated for gyroscope application by that technology. Quartz glass resonator was anchored in the center to reduce anchor-loss by controlling the geometric parameters. The Chromium / Platinum (Cr/Pt) electrodes were fabricated on the resonator body for electromagnetic actuation. The pads of these electrodes were designed such that the sacrificial Au posts remain underneath to provide mechanical support during wire bonding. The ring resonator was successfully oscillated in $n = 2$ wineglass modes. The Q-factor in air was recorded as 80 and 142 for 1st mode and 2nd mode, respectively. The mode mismatch between primary and secondary mode was recorded as 603.9 Hz. In this doctoral study, Si and quartz glass based resonator technologies were designed, fabricated and evaluated. The objective of this doctoral study was to compare SOI MEMS process and QOM MEMS process technology and point out limitations in QOM MEMS process. The QOM fabrication technology is a new finding for electromagnetically actuated resonators. The Si based ring resonator Q-factor was 20 because the resonator was evaluated in air and squeeze film damping phenomena occurring in the narrow gaps of the resonator. The fabricated resonator can be used for gyroscope application after packaging and designing feedback control module to compensate mode mismatch. The fabricated cantilevers and electromagnetic ring resonator were evaluated with PZT stacked actuator and electromagnetic actuation directed by Lorentz principle, respectively. From both evaluation schemes the results were adequate to report them as successful fabrication process of micro-resonator technology. The maximum process temperature was less than 400 ºC, thus the method has a large potential as a mean to fabricate quartz glass micro structures on various kind of substrates including the CMOS substrates. From the current study, new technologies are proposed to improve the current limitations due to fabrication imperfections. This new study can be used to fabricate MEMS vibratory gyroscopes (MVGs) and can also be implemented in other areas of MEMS technology.