Design of Analogue CMOS VLSI MEMS Sensor

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Abstract

There is an increasing demand of a highly sensitive and reliable pressure micro-sensor system, for implantable and non-implantable medical applications. The prerequisite of a miniaturized device for minimally invasive procedures, posed greater challenges in the complex integrated design of micro-system. Micro-sensor system designs in the recent advanced CMOS technologies are explored in this work for effective system miniaturization and improved performance. The material choices and geometry designs, which significantly influence the sensitivity and dynamic range of the micro-scale sensor devices, are well addressed. Co-integrations of MEMS devices with signal conditioning circuits that effectively reduce the parasitic effect are also performed for enhancing the overall system performance. In addition, system reliability is also improved with on-chip metal interconnections. The employed process technologies to a greater extent contributed to the high yield for these low cost micro-sensor systems.

This research focuses on the design of integrated CMOS MEMS capacitive pressure sensors for diverse bio-medical applications. Two monolithically integrated capacitive pressure micro-sensor systems are designed, fabricated and experimentally verified. A novel micro-electro-mechanical capacitive pressure sensor in SiGeMEMS process, vertically integrated on top of a 0.18 µm TSMC CMOS processed die is proposed. The perforated elliptic diaphragm, which is edge clamped at the semi-major axis is developed using poly-SiGe material. High performance on-chip CMOS conditioning circuits are also designed to achieve better overall sensitivity. Experimental results indicate a high sensitivity of around 0.12 mV/hPa along with a non-linearity of around 1% for the full scale range of applied pressure load. The L-clamp spring anchored diaphragm provided a wide dynamic range of around 900 hPa. Another integrated capacitive pressure micro-system, developed using the advanced standard IBM CMOS process in two geometrical designs is also proposed. A step-sided elliptic diaphragm that overcomes the CMOS process limitations is fabricated to achieve regulated membrane deflections and improved sensitivity. A foundry compatible post-process technique, for a lateral release length of 125 µm is also performed successfully on the 130 nm CMOS platform. A current cross mirroring technique is utilized to enhance the transconductance of an on-chip operational amplifier to achieve a high single stage gain. Sensitivities of the fluorosilicate sealed absolute pressure sensors were measured to be 0.07 mV/Pa and 0.05 mV/Pa for the elliptic and rectangular element, respectively. In addition, the linear capacitive transduction dynamic range was found to be 0.32 pF and 0.23 pF, respectively, for the elliptic and rectangular element.

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Table of Contents

Abstract ..... **ii**
Acknowledgements ..... **iii**
Table of Contents ..... **iv**
List of Tables ..... **viii**
List of Figures ..... **ix**
List of Acronyms and Abbreviations ..... **xiv**
List of Symbols ..... **xvi**

1. Introduction **1**
1.1 Introduction to MEMS 1
1.2 Motivation 2
1.3 Overview of the proposed research 4
1.4 Thesis organization 6

2. System overview and Literature review **8**
2.1 Introduction to micro-sensor system 8
2.2 Sensing elements 9
2.3 Pressure micro-sensor pick-off techniques 10
2.3.1 Capacitive detection 10
2.3.2 Resistive detection 11
2.4 Pressure micro-sensor system requirements and types 11
2.4.1 Types of pressure measurements 13
2.4.2 Readout circuit requirement 14
2.5 A brief literature review 15
2.5.1 MEMS capacitive pressure sensor 16
2.5.1.1 Dynamic range improvement 17
2.5.1.2 Contact and touch mode capacitive pressure sensor 18
2.5.1.3 Enhancement of sensitivity and linearity 18
2.5.2 Readout circuit review 20
2.5.2.1 Opamp basic topologies 22
2.5.2.2 Folded cascode topology 23
2.5.2.3 Low pass filter stage 25

2.5.2.4 Buffer stage 26
2.6 Conclusion 27

3. SiGeMEMS Capacitive Pressure Sensor 28
3.1 Introduction 28
3.2 Post-CMOS process 30
3.3 Design process flow 31
3.4 Design and model characterization of sensor device 33
3.4.1 Theory 33
3.4.2 Design of perforated elliptic diaphragm 38
3.4.3 Structural description and layout design 41
3.5 Model analysis 47
3.6 Post-process sealing 50
3.7 Conclusion 54

4. SiGeMEMS Sensor Readout Frontend 55
4.1 Introduction 55
4.2 Design aspect 56
4.2.1 CMOS folded cascode operational amplifier imperfection 56
4.2.2 Noise reduction technique in folded cascode operational Amplifier 58
4.2.3 Design of folded cascode operational amplifier 59
4.2.4 Pre-conditioning interface circuit 67
4.2.5 Biasing circuit for the proposed FC opamp 70
4.2.6 Sensor bias and start-up circuitry 72
4.3 Simulation results and discussion 75
4.4 Conclusion 82

5. SiGeMEMS Sensor Readout Output Stage 83
5.1 Introduction to output stage 83
5.2 Introduction to low pass filter 84
5.3 Design of transconductance (OTA) cell 85
5.3.1 Common mode feedback 88
5.3.2 Supply independent bias circuit 89
5.4 Filter design 91
5.4.1 Biquad structure 92
5.4.2 Filter topology 93

5.4.3 Simulation result of low pass filter 95
5.5 Self biased differential buffer 100
5.5.1 Design of self biased buffer 102
5.5.2 Simulation results for self biased buffer 103
5.6 Result analysis for the integrated sensor readout 106
5.7 Conclusion 109

6. Integrated MEMS pressure sensor with CMOS readout in Standard CMOS process 110
6.1 Introduction 110
6.2 Features of IBM CMOS8RF technology 112
6.3 CMOS-MEMS design process flow 113
6.4 CMOS amplifier design 115
6.4.1 Transconductance enhanced RFC 116
6.4.2 Circuit design and analysis 116
6.4.3 Implementation and results 129
6.5 Design of sensor devices 133
6.6 Fabricated CMOS-MEMS device 138
6.7 Conclusion 140

7. Post-processing of IBM CMOS MEMS Device 141
7.1 Introduction 141
7.2 Etching lithography 143
7.3 Passivation etch process 146
7.3.1 Polyimide etch 146
7.3.2 Nitride and Oxide etch 146
7.3.3 Photoresist stripping 149
7.4 Release etch process 150
7.4.1 Trench formation 150
7.4.2 Wet under etch 150
7.4.3 Dry lateral etch 151
7.4.4 Post-release etch 152
7.4.5 Post-release sealing 160
7.5 Brief summary of the post-process 161
7.6 Characterization 161
7.6.1 Discussion of mechanical characterization 161

7.6.2 Discussion of electrical characterization....168
7.7 Conclusion....171

8. Experimental Analysis and Comparison....172
8.1 Introduction....172
8.2 SiGeMEMS capacitive sensor experimental analysis....173
8.3 Experimental test on standard IBM CMOS integrated MEMS devices....176
8.3.1 Preliminary test on sensor readout....177
8.3.1.1 Chopping signal generator circuitry....177
8.3.1.2 System test circuitry....179
8.3.1.3 Preliminary test results....184
8.3.2 Comprehensive experimental analysis....185
8.4 Comparison of CMOS MEMS sensor micro-systems....189
8.4.1 Comparison of SiGeMEMS and standard CMOS MEMS sensor micro-systems....190
8.4.2 Comparison of various reported CMOS MEMS sensor micro-systems....191
8.5 Conclusion....193

9. Conclusion and Future work....194
9.1 Conclusion....194
9.2 Future work....197

Bibliography....198
Appendix I....209
Appendix II....215
Appendix III....223

List of Tables

Table 2.1: Target specifications of the design 27
Table 4.1: Aspect ratios of M-Chopper FC opamp Stage 79
Table 4.2: Aspect ratios of trans-impedance stage, pre-amp & CMFB 79
Table 4.3: Aspect ratios of sensor bias and start-up circuit 80
Table 4.4: Aspect ratios of FC opamp biasing network 80
Table 4.5: Features of proposed FC opamp 82
Table 5.1: LPF simulation results 96
Table 5.2: Aspect ratios of the Gm-C filter and component values 98
Table 5.3: Comparison of different filter designs 100
Table 5.4: Simulation output of the buffer 104
Table 5.5: Aspect ratio of the buffer circuit and component values 105
Table 6.1: Performance comparison of different RFC circuits 132
Table 6.2: Aspect ratios for the proposed amplifier 133
Table 7.1: Process details for dry Etch 153
Table 7.2: Feature comparison of various reported CMOS-MEMS Devices 154
Table 7.3: Dimension Icon System setup – DIM 4000 166
Table 7.4: AFM analysis results 167

List of Figures

Fig. 1.1: Cross section of, (a) CMOS + SiGeMEMS integrated pressure micro-sensor system, (b) Standard CMOS MEMS integrated pressure micro-sensor system 4

Fig. 2.1: Types of pressure measurement 13

Fig. 2.2: Diaphragm pressure sensor 16

Fig. 3.1: pre-CMOS process 29

Fig. 3.2: Interleaved process 29

Fig. 3.3: post-CMOS process 29

Fig. 3.4: Cross section of IMEC SiGeMEMS process 30

Fig. 3.5: Process flow of SiGeMEMS 32

Fig. 3.6: System block diagram of the integrated MEMS capacitive pressure sensor with CMOS readout 32

Fig. 3.7: Perforated elliptic diaphragm, clamped at the semi-major axis using clamp springs 39

Fig. 3.8: Stress-Strain relationship curve 41

Fig. 3.9: Cross-section of the target CMOS integrated SiGeMEMS process for integrated MEMS pressure sensor 43

Fig. 3.10: Layout design of the elliptic diaphragm 45

Fig. 3.11: A portion of the elliptic diaphragm showing the layout design methodology 46

Fig. 3.12: Package layout of CMOS+MEMS design 48

Fig. 3.13: COMSOL model analysis procedure 49

Fig. 3.14: Displacement analysis of the elliptic diaphragm 50

Fig. 3.15: Standalone SiGeMEMS processed top wafer 52

Fig. 3.16: Backside etched top wafer 52

Fig. 3.17: Cross-section of integrated SiGe CMOS+MEMS sensor (bottom wafer) 53

Fig. 3.18: Cross section of MEMS integrated sealed absolute pressure sensor 53

Fig. 4.1: Block diagram of sensor readout frontend 55

Fig. 4.2: Folded cascode operational amplifier 57

Fig. 4.3: Proposed FC opamp with conventional chopper stabilization 61

Fig. 4.4: Conventional chopper stabilization circuit 62

Fig. 4.5: Modified chopper stabilized g_m boosted FC opamp with pre-conditioning circuit 64

Fig. 4.6: Pole - Zero plots 65

Fig. 4.7: Transmission gate chopper 66

Fig. 4.8: Differential difference amplifier used as CMFB Circuit 66
Fig. 4.9: Pre-conditioning interface circuit 67
Fig. 4.10: Trans-impedance amplifier 68
Fig. 4.11: Pre-amp Buffer 69
Fig. 4.12: Current mirror biasing circuitry 71
Fig. 4.13: Sensor bias and start-up circuitry 72
Fig. 4.14: Cascode current mirror for sensor biasing and startup 73
Fig. 4.15: Sensor readout frontend layout design 76
Fig. 4.16: Layout design of bias circuitry for start-up, pre-amp buffer and trans-impedance amplifier 77
Fig. 4.17: Layout design of start-up, pre-amp buffer and trans-impedance amplifier 77
Fig. 4.18: Input transistors layout design 78
Fig. 4.19: Comparison of chopper outputs 78
Fig. 4.20: AC analysis of M-Chopper stabilized FC opamp & conventional two stage FC opamp 80
Fig. 4.21: Harmonic distortion of M-Chopper stabilized FC opamp 81
Fig. 4.22: Noise in the proposed FC opamp 81
Fig. 4.23: Single ended transient responses of proposed FC opamp 81
Fig. 5.1: Block diagram of sensor readout output stage 83
Fig. 5.2: Transconductance cell schematic 86
Fig. 5.3: Small signal model of single stage OTA with negative resistive load 88
Fig. 5.4: Block diagram of common mode control 89
Fig. 5.5: Biasing circuit for OTA and CMFB circuits 91
Fig. 5.6: Floating capacitor balanced differential integrator 93
Fig. 5.7: Fourth order elliptic filter topology 95
Fig. 5.8: AC response & harmonic distortion of LPF with separate excitation 97
Fig. 5.9: Layout design of LPF 99
Fig. 5.10: Block diagram description of signal flow in sensor readout 101
Fig. 5.11: Negative feedback in buffered opamp 101
Fig. 5.12: Self biased differential buffer 103
Fig. 5.13: Layout design of self biased differential buffer 104
Fig. 5.14: (a) Gain response of the sensor readout, (b) Phase response of the sensor readout 106
Fig. 5.15: Transient analysis of the sensor readout 107

Fig. 5.16: Layout design of the entire sensor readout showing frontend and output stages 108
Fig. 6.1: Cross section of IBM CMRF8SF DM process 111
Fig. 6.2: Standard CMOS-MEMS process flowchart 114
Fig. 6.3: Proposed transconductance doubling RFC.....118
Fig. 6.4: One half of the proposed g_m doubling RFC with large and small signal current directions.....120
Fig. 6.5: Node currents at node N1 120
Fig. 6.6: (a) Small signal equivalent of one half of proposed transconductance doubling RFC 123
Fig. 6.6: (b) Current sources are merged for small signal analysis.....124
Fig. 6.6: (c) Output impedances are combined for further simplification for small signal analysis 125
Fig. 6.6: (d) Simplified small signal equivalent of one half of the proposed transconductance doubling RFC 125
Fig. 6.6: (e) Simplified equivalent circuit for small signal gain analysis 125
Fig. 6.7: Pulse response of the proposed amplifier 129
Fig. 6.8: AC response of single stage g_m enhanced RFC 130
Fig. 6.9: Transient analysis of the proposed two stage g_m doubling RFC.....131
Fig. 6.10: AC analysis of the proposed two stage g_m doubling RFC 131
Fig. 6.11: THD analysis for the proposed enhanced gm RFC 132
Fig. 6.12: Elliptic geometry with step edge 135
Fig. 6.13: Rectangular geometry with bottom electrode.....136
Fig. 6.14: Elliptic diaphragm defromation analysis.....137
Fig. 6.15: Rectangular diaphragm defromation analysis 137
Fig. 6.16: Pyxis layout window (a) Amplifier circuit layout (b) CMOS integrated design snapshot 138
Fig. 6.17: Integrated CMOS MEMS devices in 130 nm IBM CMOS process 139
Fig. 6.18: Fabricated step edged elliptic diaphragm complying with the standard CMOS process.....139
Fig. 7.1: Process steps for sensor release etch 142
Fig. 7.2: DWW Mask writing system and setup 144
Fig. 7.3: Resist developed sensor capacitances, (a) Elliptic diaphragm, (b) Rectangular diaphragm.....145
Fig. 7.4: Photo of RIE chamber during CHF_3 plasma etch 148
Fig. 7.5: Diaphragms after polyimide etch 148

Fig. 7.6: Release etch, (a) partial release of elliptic diaphragm, (b) complete sacrificial Oxide and Nitride etch and release of elliptic diaphragm, and, (c) Fully released rectangular diaphragm.....155
Fig. 7.7: Cross-section diagrams of the step-by-step MEMS release process, (a) Initial CMOS chip with circuitry and unreleased MEMS capacitors, (b) Lithography with thick resist (DWW patterning mask 1), (c) After passivation etch, (d) Lithography with thin resist (DWW pattering mask 2), (e) After dry trench etch, (f) Lithography with thin resist (DWW pattering mask 2 repeat with sidewall protection), (g) After wet etch and following dry etch (composite etch), (h) after post release etch. (i) After post release fluorosilicate sealing 158
Fig. 7.8: Flowchart of the sensor release process sequence.....159
Fig. 7.9: Fluorosilicate glass sealed rectangular diaphragm.....160
Fig. 7.10: Bruker Dimension Icon AFM system loaded with the specimen 162
Fig. 7.11: The complete AFM analysis system.....163
Fig. 7.12: Atomic Force Microscope step-height analysis, (a) Chip image from AFM microscope after partial polyimide etch, (b) Step height in 3D after partial polyimide etch, (c) Top-view of polyimide etch and step height analysis plot after partial polyimide etch and (d) Top view (white patches indicating resist remnants after resist strip-off) and step height analysis plot after complete passivation etch.....165
Fig. 7.13: DC probe station: Agilent device analyzer B1500A with 5 MHz pulsed source 167
Fig. 7.14: Electrical contact analysis, (a) Before polyimide etch (with full passivation intact), (b) After Nitride etch (with Oxide layer still present).....169
Fig. 7.15: Electrical contact analysis of exposed diaphragm after etching the oxide layer of passivation, (a) Resistance variation, (b) Current variation.....170
Fig. 7.16: Electrical contact analysis between MA (top electrode) and LY (bottom electrode).....170
Fig. 8.1: Overview of the experimental setup.....172
Fig. 8.2: Microscopic photograph of the integrated SiGeMEMS sensor die 174
Fig. 8.3: Packaged SiGeMEMS micro-system with option of ESD taped lid 174
Fig. 8.4: SiGeMEMS chip experimental test setup.....175
Fig. 8.5: Capacitance variation with applied pressure load 175

Fig. 8.6: Voltage output of the sensor micro-system with applied pressure 176
Fig. 8.7: Oscillator diagram of HEF4060B 178
Fig. 8.8: Logic diagram of HEF4060B 178
Fig. 8.9: Crystal oscillator circuit diagram using HEF4060B 178
Fig. 8.10: (a) Bottom view of PGA 108M package
(b) Top view of the packaged IC 179
Fig. 8.11: Drawing equivalent of PGA 108M package 180
Fig. 8.12: Bonding diagram showing bondpads to bondpins connections 181
Fig. 8.13: IC in ZIF socket 182
Fig. 8.14: Bottom view of ZIF socket showing the soldered pins 182
Fig. 8.15: System testing setup 183
Fig. 8.16: Part of the test circuit connections 183
Fig. 8.17: Input signal to the opamp 184
Fig. 8.18: Modulated signal at the output of opamp 184
Fig. 8.19: Experimental test setup for sensor
transduction performance measurement 187
Fig. 8.20: Post-processed CMOS MEMS naked die
being wire-bonded on to the PCB 187
Fig. 8.21: Performance of the elliptic and rectangular devices 188
Fig. 8.22: Sensing circuit response with applied pressure 188
Fig. 8.23: Temperature dependencies of (a) Elliptic element,
(b) Rectangular element 189

List of Acronyms and Abbreviations

AFM	Atomic Force Microscope
APM	Ammonia hydroxide-hydrogen Peroxide
ADC	Analog to Digital Converter
BEOL	Back End Of Line
BSIM	Berkeley Short-channel IGFET Model
CAD	Computer Aided Design
CHS	Chopper Stabilization
CMFB	Common Mode Feed Back
CMRR	Common Mode Rejection Ratio
CMOS	Complementary Metal Oxide Semiconductor
DRC	Design Rule Check
DRIE	Deep Reactive Ion Etching
DIP	Dual line in package
DUT	Device Under Test
DWW	Direct on wafer writing
EDA	Electronic Design Automation
ESD	Electrostatic Discharge
FC opamp	Folded Cascode Operational Amplifier
FC out+	Positive going output voltage of folded cascode opamp
FC out-	Negative going output voltage of folded cascode opamp
FC_out_{diff}	Differential output voltage of folded cascode opamp
FEA	Finite Element Analysis
FEOL	Front End Of Line
GBW	Gain Bandwidth Product
GUI	Graphical User Interface
HPM	Hydrochloric acid-hydrogen peroxide
IC	Integrated Circuit
ICMR	Input Common Mode Range
ICP	Inductively Coupled Plasma
IEEE	Institute of Electrical and Electronics Engineers Inc.
LPF	Low Pass Filter
LPCVD	Low Pressure Chemical Vapor Deposition

Lp_OUT+	Positive going output voltage of LPF
Lp_OUT-	Negative going output voltage of LPF
M-Chopper	Modified Chopper Stabilization
MEMS	Micro Electromechanical System
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MST	Minimum Settling Time
MUMPS	Multi-User MEMS Processes
OTA	Operational Transconductance Amplifier
PMMA	Poly methyl methacrylatel
PDMS	Polydimethylsiloxane
PGA	Pin Grid Array
PSRR	Power Supply Rejection Ratio
RF	Radio Frequency
RFC	Recycled Folded Cascode opamp
RIE	Reactive Ion Etching
$Sensor_{out+}$	Positive going output voltage of the sensor
$Sensor_{out+}$	Negative going output voltage of the sensor
SNR	Signal to Noise ratio
SDL	Schematic Driven Layout
SIP	System in package
THD	Total Harmonic Distortion
UGB	Unity Gain Bandwidth
VL_OUT_{diff}	Differential Output voltage of OTA
VM	Virtual Metrology
ZIF	Zero Insertion Force

List of Symbols

C	Capacitance	Farad
ε_r	Relative Permittivity	Farad per meter
ε_o	Permittivity of free space	Farad per meter
A	Area of the capacitor plate	Meter Square
λ	Channel length modulation	Micrometer
μ_n	Electron mobility	Meter square/Volts seconds
μm	Micrometer	
ε_{xx}	Normal strain in x direction	
ε_{yy}	Normal strain in y direction	
ε_{xy}	Shear strain	
w	Deflection of the plate	Micrometer
σ_{xx}	Normal stress in x direction	Newton/meter square
σ_{yy}	Normal stress in y direction	Newton/meter square
τ_{xy}	Shear stress	Pascal
E	Young's Modulus	Newton/meter square
υ	Poisson's ratio	
P_o	Applied Pressure	Hecto-Pascal
D	Flexural rigidity	Newton meter square
M_x	Bending moments in x direction	Newton Meters
M_y	Bending moments in y direction	Newton Meters
M_{xy}	Shear moments in x direction	Newton Meters
Pa	Pascal	Newton/meter square
g_m	Transconductance	Ampere/microvolt
k	Boltzmann's constant	Joules/Kelvin
T	Absolute temperature	Kelvin
R	Resistance	Ohms
B	Noise bandwidth	Hertz
W	Channel width of the MOSFET	Micrometer
L	Channel length of the MOSFET	Micrometer
I_D	DC Drain current of MOSFET	Amperes
i_d	Small signal drain current of MOSFET	Amperes
C_{ox}	Gate oxide capacitance	Farad
V_{cm}	Common mode voltage	Volts
A_{FC}	Open loop gain	Decibels
Q	Quality factor	