Nanoelectromechanical Systems
Contents

PREFACE  ................................................................. vii

PHYSICAL CONSTANTS  ............................................... ix

NOTATIONS  ........................................................... xi

CHAPTER 1. FROM MEMS TO NEMS  ................................... 1
   1.1. Micro- and nanoelectromechanical systems: an overview   1
   1.2. Conclusion  .................................................... 9

CHAPTER 2. TRANSDUCTION ON THE NANOMETRIC SCALE AND THE
            NOTION OF NOISE  .......................................... 13
   2.1. Mechanical transfer function  ................................ 14
   2.2. Transduction principles  ...................................... 20
      2.2.1. The actuation of nanostructures  ....................... 23
      2.2.2. Detection  ................................................ 31
   2.3. Self-oscillation and noises  ................................ 49
   2.4. Conclusion  .................................................... 58

CHAPTER 3. MONOLITHIC INTEGRATION OF NEMS WITH THEIR
            READOUT ELECTRONICS  ................................... 61
   3.1. Foreword  ..................................................... 61
      3.1.1. Why integrate NEMS with their readout electronics? 61
      3.1.2. What are the differences between MEMS-CMOS and NEMS-CMOS? 62
   3.2. The advantages of and main approaches to monolithic integration 64
      3.2.1. A comparison of integration schemes and their electrical performance 64
3.2.2. Closed-loop NEMS-CMOS oscillators: the essential building block for NEMS-based frequency sensors .................................................. 69
3.2.3. Overview of the main achievements from the perspective of manufacturing technology ................................................................. 70
3.3. Analysis of some significant achievements from the perspective of transduction .............................................................. 75
  3.3.1. Examples of capacitive NEMS-CMOS .................................. 75
  3.3.2. Examples of piezoresistive NEMS-CMOS .......................... 82
  3.3.3. Alternative approaches .................................................... 85
3.4. Conclusions and future perspectives ........................................ 86

CHAPTER 4. NEMS AND SCALING EFFECTS ........................................ 89
  4.1. Introduction .............................................................................. 89
    4.1.1. Intrinsic losses ................................................................. 96
    4.1.2. Extrinsic losses ............................................................... 97
  4.2. Near field effect in a nanostructure: Casimir force ................. 102
    4.2.1. Intuitive explanation of the Casimir force ...................... 102
    4.2.2. The problem ................................................................. 105
    4.2.3. Rigorous calculation of the Casimir force
    between two silicon slabs ......................................................... 107
    4.2.4. Impact of the Casimir force in a nano-accelerometer ......... 113
    4.2.5. Conclusion ................................................................. 117
  4.3. Example of “intrinsic” scaling effects: electrical conduction laws .............................................................. 117
    4.3.1. Electrical resistivity ......................................................... 117
    4.3.2. Piezoresistive effect ......................................................... 125
  4.4. Optomechanical nano-oscillators and quantum optomechanics .... 136
  4.5. Conclusion ................................................................. 147

CHAPTER 5. CONCLUSION AND APPLICATION PROSPECTS:
FROM FUNDAMENTAL PHYSICS TO APPLIED PHYSICS ...................... 149

APPENDIX .................................................................................. 167

BIBLIOGRAPHY ......................................................................... 175

INDEX ..................................................................................... 193
Since the invention of the first calculating machine by Blaise Pascal in 1642, mechanical systems have contributed a great deal to the industrial revolution and continue to play a fundamental role in our daily lives.

In the 1980s, mechanical systems moved to the micrometric scale and became micromechanical systems. Their lateral size ranges from several microns to several hundreds of microns for a thickness of 10 µm. These are transducers and their uniqueness lies in their ability to transform mechanical energy (movement, constraint) into electrical energy. The most well-known transducers are micro-accelerometers, gyrometers and pressure sensors; they have countless applications that are used by the general public (airbags, mobile phones, games, etc.).
Several years ago, mechanics combined with electronics became nanometric. Nanosystems therefore infiltrated the world of mesoscopic physics, working at the molecular or supramolecular scale at sizes varying from 1 nm to 1 µm. These objects are the latest probes capable of measuring molecular interactions in physics, chemistry or biophysics. They cover a large number of applications, ranging from signal treatment to ultra-weak stimuli detection. Specifically, their low masses ($10^{-15}$ to $10^{-18}$ g) make them ideal candidates for identifying macromolecules in the living world or measuring the cell strength. The potential of these components suggests that they will play a major role in medical diagnosis, environmental monitoring and food quality monitoring. This book will present the theoretical and technological elements of nanosystems. I hope it will prove to be a useful tool for future readers and will provide a picture – although probably incomplete – of current and future research in the field.

Laurent DURAFFOURG
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Physical Constants

$\varepsilon_0$: vacuum permittivity ($8.85 \times 10^{-12}$ F)

$\mu_0$: vacuum permeability ($4\pi \times 10^{-7}$ H.m$^{-1}$)

$h$: Planck constant ($6.62 \times 10^{-34}$ J.s)

$\hbar$: reduced Planck constant ($h/2\pi$)

$k_B$: Boltzmann constant ($1.38 \times 10^{-23}$ J.K$^{-1}$)

$m_e$: electron mass ($9.105 \times 10^{-31}$ kg)

$Da$: 1 Dalton–atomic mass unit ($1.6605 \times 10^{-24}$ kg)

$e$: electron charge ($1.602 \times 10^{-19}$ C)

$N_A$: Avogadro number ($6.022 \times 10^{23}$)

$c$: speed of light ($2.997 \times 10^8$ m.s$^{-1}$)
Notations

$x, y, z$: displacement (m)

$v_x, v_y, v_z$: speeds (m.s$^{-1}$)

$a_x, a_y, a_z$: accelerations (m.s$^{-2}$)

$m$: total NEMS mass (kg)

$m_{\text{eff}}$: effective NEMS mass (kg)

$k$: stiffness of NEMS (N.m$^{-1}$)

$k_b$: Boltzmann constant (J.K$^{-1}$)

$k_{\text{eff}}$: effective stiffness of NEMS (N.m$^{-1}$)

$k_d$: Duffing stiffness (N.m$^{-3}$)

$l$: length (m)

$w$: width (m)

$t$: thickness (m)

$g$: electrostatic gap (m)

$E$: Young’s module (P)

$I$: moment of inertia (m$^4$)
\( \sigma \): constraint (P)

\( \varepsilon \): elongation

\( \rho \): density (kg.m\(^{-3}\))

\( T \): temperature (K)

\( \ell \): mean free path (m)

\( q \): charge (C)

\( C_{th} \): thermal conductance (J.K\(^{-1}\))

\( G_{th} \): thermal conductance (W.K\(^{-1}\))

\( R_{th} \): thermal resistance (W\(^{-1}\).K)

\( \sigma_{th} \): thermal conductivity (W.K\(^{-1}\).m\(^{-1}\))

\( N_{a}, N_{d} \): level of acceptor (P), donor (N) dopants (cm\(^{-3}\))

\( R \): electrical resistance (\(\Omega\))

\( C \): electrical capacitance (F)

\( \mu_e \): electrical mobility (m\(^2\).V\(^{-1}\).s\(^{-1}\))

\( \rho_e \): electrical resistivity (ohm.m)

\( \Delta R/R \): relative resistance variation

\( P_{th} \): dissipated thermoelastic power (W)

\( P_e \): dissipated electrical power – Joule effect (W)

\( G, \gamma_G \): piezoresistive gauge factor

\( Q \): quality factor

\( f_1 \): resonance frequency of the first mechanical mode of NEMS (Hz)
$f_n$: resonance frequency of the nth mechanical mode of NEMS (Hz)

$\delta f$: frequency dispersion around the nominal frequency (Hz)

$\Delta f$: increase of frequency in relation to nominal frequency (Hz)

$\omega_i$: angular frequency ($2\pi f_i$)

$\omega_n$: angular frequency ($2\pi f_n$)