

References

1. G.G. Coriolis. Mémoire sur les équations du mouvement relatif des systèmes de corps. *Journal de l'école Polytechnique*, Vol 15, pp. 142154, 1835.
2. IEEE Std 1431-2004. IEEE Standard Specification Format Guide and Test Procedure for Coriolis Vibratory Gyros.
3. IEEE Std 528-2001. IEEE Standard for Inertial Sensor Terminology.
4. N. Yazdi, F. Ayazi, and K. Najafi. Micromachined Inertial Sensors. *Proc. of IEEE*, Vol. 86, No. 8, August 1998.
5. H. Xie and G. K. Fedder. Integrated Microelectromechanical Gyroscopes. *Journal of Aerospace Engineering*, Vol. 16, No. 2, April 2003, pp. 65-75.
6. P. Greiff, B. Boxenhorn, T. King, and L. Niles. Silicon monolithic micromechanical gyroscope. *Tech. Dig. 6th Int. Conf. Solid-State Sensors and Actuators (Transducers'91)*, San Francisco, CA, June 1991, pp. 966-968.
7. S. D. Orlosky and H. D. Morris. Quartz rotation (rate) sensor. *Proc. Sensor Expo, Cleveland, OH*. 1994, pp. 171-177.
8. R. R. Ragan and D. D. Lynch. Inertial technology for the future, Part X: Hemispherical resonator gyro. *IEEE Trans. Aerosp. Electron. Syst.*, vol. AES-20, July 1984. p. 432
9. J. Bernstein, S. Cho, A. T. King, A. Kourepenis, P. Maciel, and M. Weinberg. A micromachined comb-drive tuning fork rate gyroscope. *Proc. IEEE Microelectromechanical Systems, Fort Lauderdale, FL*, Feb. 1993, pp. 143-148.
10. M. W. Putty and K. Najafi. A micromachined vibrating ring gyroscope. *Tech. Dig. Solid-State Sens. Actuator Workshop, Hilton Head Island, SC*, June 1994, pp. 213-220.
11. Hopkin, I. D. Vibrating gyroscopes (automotive sensors). *IEEE Colloquium on Automotive Sensors. Digest No. 1994/170. Solihull, UK*, Sept. 1994, pp. 1-4.
12. Tanaka, K., Mochida, Y., Sugimoto, S., Moriya, K., Hasegawa, T., Atsuchi, K., and Ohwada, K. A micromachined vibrating gyroscope. *Proc., Eighth IEEE Int. Conf. on Micro Electro Mechanical Systems (MEMS '95)*, Amsterdam, Netherlands, Jan. 1995, pp. 278-281.
13. Clark, W. A., Howe, R. T., and Horowitz, R. Surface micromachined Z-axis vibratory rate gyroscope. *Technical Digest. Solid-State Sensor and Actuator Workshop, Hilton Head Island, S.C.*, June 1996, pp. 283-287.
14. Juneau, T., Pisano, A. P., and Smith, J. H. Dual axis operation of a micromachined rate gyroscope. *Proc., IEEE 1997 Int. Conf. on Solid State Sensors and Actuators (Transducers '97)*, Chicago, June 1997, pp. 883-886.
15. M. Lutz, W. Golderer, J. Gerstenmeier, J. Marek, B. Maihofer, S. Mahler, H. Munzel, and U. Bischof. Aprecision yaw rate sensor in silicon micromachining, *Transducers 1997, Chicago, IL*, June 1997, pp. 847-850.
16. T. K. Tang, R. C. Gutierrez, C. B. Stell, V. Vorperian, G. A. Arakaki, J. T. Rice, W. J. Li, I. Chakraborty, K. Shcheglov, J. Z. Wilcox, and W. J. Kaiser. A packaged silicon MEMS vibratory gyroscope for microspacecraft. *Proc. IEEE Micro Electro Mechanical Systems Workshop (MEMS'97)*, Japan, 1997, pp. 500-505.

17. D. R. Sparks, S. R. Zarabadi, J. D. Johnson, Q. Jiang, M. Chia, O. Larsen, W. Higdon, and P. Castillo-Borelley. A CMOS integrated surface micromachined angular rate sensor: It's automotive applications. *Tech. Dig. 9th Int. Conf. Solid-State Sensors and Actuators (Transducers'97)*, Chicago, IL, June 1997, pp. 851-854.
18. Y. Oh, B. Lee, S. Baek, H. Kim, J. Kim, S. Kang, and C. Song. A surface-micromachined tunable vibratory gyroscope. *Proc. IEEE Micro Electro Mechanical Systems Workshop (MEMS'97)*, Japan, 1997, pp. 272-277.
19. K. Y. Park, C. W. Lee, Y. S. Oh, and Y. H. Cho. Laterally oscillated and force-balanced micro vibratory rate gyroscope supported by fish hook shape springs. *Proc. IEEE MicroElectro Mechanical Systems Workshop (MEMS'97)*, Japan, 1997, pp. 494-499.
20. R. Voss, K. Bauer, W. Ficker, T. Gleissner, W. Kupke, M. Rose, S. Sassen, J. Schalk, H. Seidel, and E. Stenzel. Silicon angular rate sensor for automotive applications with piezoelectric drive and piezoresistive read-out. *Tech. Dig. 9th Int. Conf. Solid-State Sensors and Actuators (Transducers'97)*, Chicago, IL, June 1997, pp. 879-882.
21. R. Hulsing. MEMS inertial rate and acceleration sensor. *IEEE AES Systems Magazine*. November 1998, pp. 17-23.
22. A. Kourepenis, J. Bernstein, J. Connely, R. Elliot, P. Ward, and M. Weinberg. Performance of MEMS inertial sensors. *Proc. IEEE Position Location and Navigation Symposium*, 1998, pp. 1-8.
23. Mochida, Y., Tamura, M., and Ohwada, K. A micromachined vibrating rate gyroscope with independent beams for the drive and detection modes. *Proc., Twelfth IEEE Int. Conf. on Micro Electro Mechanical Systems (MEMS '99)*, Orlando, FL, Jan. 1999, pp. 618-623.
24. Funk, K., Emmerich, H., Schilp, A., Offenberger, M., Neul, R., and Larmer, F. A surface micromachined silicon gyroscope using a thick polysilicon layer. *Proc., Twelfth IEEE Int. Conf. on Micro Electro Mechanical Systems (MEMS '99)*, Orlando, FL, Jan. 1999, pp. 57-60.
25. Park, K. Y., Jeong, H. S., An, S., Shin, S. H., and Lee, C. W. Lateral gyroscope suspended by two gimbals through high aspect ratio ICP etching. *Proc., IEEE 1999 Int. Conf. on Solid State Sensors and Actuators (Transducers '99)*, Sendai, Japan, June 1999, pp. 972-975.
26. S. Lee, S. Park, J. Kim, and D. Cho. Surface/bulk micromachined single-crystalline-silicon micro-gyroscope. *IEEE/ASME Journal of Microelectromechanical Systems*, Vol.9, No.4 Dec. 2000, pp. 557-567.
27. Jiang, X., Seeger, J. I., Kraft, M., and Boser, B. E. A monolithic surface micromachined Z-axis gyroscope with digital output. *Digest of Technical Papers, 2000 Symposium on VLSI Circuits, Honolulu*, June 2000, pp. 16-19.
28. H. Xie and G. K. Fedder. A CMOS-MEMS lateral-axis gyroscope. *Proc. 14th IEEE Int. Conf. Microelectromechanical Systems, Interlaken, Switzerland*, Jan. 2001, pp. 162-165.
29. H. Luo, X. Zhu, H. Lakdawala, L. R. Carley, and G. K. Fedder. A copper CMOS- MEMS z-axis gyroscope. *Proc. 15th IEEE Int. Conf. Microelectromechanical Systems, Las Vegas, NV*, Jan. 2001, pp. 631-634.
30. W. Geiger, W.U. Butt, A. Gaisser, J. Fretch, M. Braxmaier, T. Link, A. Kohne, P. Nommensen, H. Sandmaier, and W. Lang. Decoupled Microgyros and the Design Principle DAVED. *Sensors and Actuators A (Physical)*, Vol. A95, No.2-3, Jan. 2002, pp. 239-249.
31. J. A. Geen, S. J. Sherman, J. F. Chang, and S. R. Lewis. Single-chip surface-micromachining integrated gyroscope with 50 deg/hour root Allan variance. *Dig. IEEE Int. Solid-State Circuits Conf., San Francisco, CA*, Feb. 2002, pp. 426-427.
32. Seshia, A. A., Howe, R. T., and Montague, S. An integrated microelectromechanical resonant output gyroscope. *Proc., The Fifteenth IEEE Int. Conf. on Micro Electro Mechanical Systems (MEMS 2002)*, Las Vegas, Jan. 2002, pp. 722-726.
33. G. He and K. Najafi. A single crystal silicon vibrating ring gyroscope. *Proc., The Fifteenth IEEE Int. Conf. on Micro Electro Mechanical Systems (MEMS 2002)*, Las Vegas, Jan. 2002, pp. 718-721.
34. H. Xie and G. K. Fedder. Fabrication, Characterization, and Analysis of a DRIE CMOS-MEMS Gyroscope. *IEEE Sensors Journal*, Vol. 3, No. 5, 2003, pp. 622-631.

35. Karnick, D.; Ballas, G.; Koland, L.; Secord, M.; Braman, T.; Kourepenis, T. Honeywell gun-hard inertial measurement unit (IMU) development. *Position Location and Navigation Symposium, PLANS 2004*. 26-29 April 2004 Page(s):49 - 55.
36. Byoung-doo Choi; Sangjun Park; Hyoungho Ko; Seung-Joon Paik; Yonghwa Park; Geunwon Lim; Ahra Lee; Sang Chul Lee; Carr, W.; Setiadi, D.; Mozulay, R.; Dong-il Cho. The first sub-deg/hr bias stability, silicon-microfabricated gyroscope. *Solid-State Sensors, Actuators and Microsystems, 2005. TRANSDUCERS '05*. 5-9 June 2005, pp. 180 - 183.
37. A. Sharma, M.F. Zaman, and F.A. Ayazi. 0.2 deg/hr Micro-Gyroscope with Automatic CMOS Mode Matching. *IEEE International Solid-State Circuits Conference, 2007. ISSCC 2007*. pp. 386 - 610.
38. M.F. Zaman, A. Sharma, and F.A. Ayazi. High Performance Matched-Mode Tuning Fork Gyroscope. *Tech. Dig 19th IEEE International Conference on Micro-Electromechanical Systems Conference 2006 (MEMS 2006)*. Istanbul, Turkey, Jan. 2006, pp. 66-69.
39. T. J. Brosnihan, J. M. Bustillo, A. P. Pisano, and R. T. Howe. Embedded interconnect and electrical isolation for high-aspect-ratio, SOI inertial instruments. *Transducers 1997, Chicago, IL*, June 1997, pp. 637-640.
40. Egyptian Museum, Egyptian Center for Documentation of Cultural and Natural Heritage. www.etrnaleypt.org
41. A. Persson, The Coriolis Effect A Conflict Between Common Sense and Mathematics. The Swedish Meteorological and Hydrological Institute, Norrkping, Sweden.
42. N. Barbour, and G. Schmidt. Inertial Sensor Technology Trends. *IEEE Sensors Journal, Vol. 1, No. 4*, Dec 2001, pp. 332-339.
43. W.A. Clark, R.T. Howe, and R. Horowitz. Surface Micromachined Z-Axis Vibratory Rate Gyroscope. *Proceedings of Solid-State Sensor and Actuator Workshop*, June 1994.
44. A. Shkel, R.T. Howe, and R. Horowitz. Micromachined Gyroscopes: Challenges, Design Solutions, and Opportunities. *Int. Workshop on Micro-Robots, Micro-Machines and Systems, Moscow, Russia, 1999*.
45. A. Shkel, R. Horowitz, A. Seshia, S. Park and R.T. Howe. Dynamics and Control of Micromachined Gyroscopes *American Control Conference, CA*, 1999.
46. S. Park and R. Horowitz. Adaptive Control for Z-Axis MEMS Gyroscopes. *American Control Conference, Arlington, VA*, June 2001.
47. R.P. Leland. Adaptive Tuning for Vibrational Gyroscopes. *Proceedings of IEEE Conference on Decision and Control, Orlando, FL*, Dec. 2001.
48. US 5,992,233. W.A. Clark. Micromachined z-Axis Vibratory Gyroscope. Nov. 1999.
49. US 6,122,961. J.A. Geen, and D.W. Carow. Micromachined Gyros. Sept. 2000.
50. US 6,089,089. Y.W. Hsu. Multi-Element Micro Gyro. April 1999.
51. C.W. Dyck, J. Allen, and R. Hueber. Parallel Plate Electrostatic Dual Mass Oscillator. *Proceedings of SPIE SOE, CA*, 1999.
52. X. Li, R. Lin, and K.W. Leow. Performance-Enhanced Micro-Machined Resonant Systems with Two-Degrees-of-Freedom Resonators. *Journal of Micromech, Microeng., Vol. 10*, 2000, pp. 534-539.
53. T. Usada. Operational Characteristics of Electrostatically Driven Torsional Resonator with Two-Degrees-of-Freedom. *Sensors and Actuators A*, Vol. 64, 1998, pp. 255-257.
54. W. Geiger, B. Folkmer, U. Sobe, H. Sandmaier, and W. Lang. New Designs of Micromachined Vibrating Rate Gyroscopes with Decoupled Oscillation Modes. *Sensors and Actuators A*, Vol. 66, 1998, pp. 118-124.
55. E. Netzer, and I. Porat. A Novel Vibratory Device for Angular Rate Measurement. *Journal of Dynamic Systems, Measurement and Control*, Dec. 1995.
56. A. Seshia. Design and Modeling of a Dual Mass SOI-MEMS Gyroscope. *M.S. Thesis, BSAC, U.C. Berkeley*, 1999.
57. D.A. Koester, R. Mahadevan, B. Hardy, and K.W. Markus. MUMPs Design Handbook, Revision 5.0. *Cronos Integrated Microsystems*, 2000.
58. L. Lin, R.T. Howe, and A.P. Pisano. Microelectromechanical Filters for Signal Processing. *Journal of Microelectromechanical Systems, Vol. 7*, Sept. 1998.

59. Lemkin. Micro Accelerometer Design with Digital Feedback Control. *Ph.D. Thesis, BSAC, U.C. Berkeley*, 1997.
60. H. Xie and G.K. Fedder. A DRIE CMOS-MEMS Gyroscope. *IEEE Sensors 2002 Conference, June 2002, Orlando, FL*.
61. A. Shkel, R.T. Howe, and R. Horowitz. Modeling and Simulation of Micromachined Gyroscopes in the Presence of Imperfections. *International Conference on Modeling and Simulation of Microsystems*, Puerto Rico, 1999, pp. 605-608.
62. W.A. Clark. Micromachined Vibratory Rate Gyroscope. *Ph.D. Thesis, BSAC, U.C. Berkeley*, 1994.
63. C. Acar, and A. Shkel. Inherently Robust Micromachined Gyroscopes with 2-DOF Sense-Mode Oscillator. *Journal of Microelectromechanical Systems*. Vol. 15, No. 2, pp. 380-387, 2006.
64. C. Acar, and A. Shkel. An Approach for Increasing Drive-Mode Bandwidth of MEMS Vibratory Gyroscopes. *Journal of Microelectromechanical Systems*. Vol. 14, No. 3, pp. 520-528, 2005.
65. C. Acar, and A. Shkel. Structurally Decoupled Micromachined Gyroscopes with Post-Release Capacitance Enhancement. *Journal of Micromechanics and Microengineering*. Vol.15, pp. 1092-1101, 2005.
66. C. Acar, and A. Shkel. Structural Design and Experimental Characterization of Torsional Micromachined Gyroscopes with Non-Resonant Drive-Mode. *Journal of Micromechanics and Microengineering*. Vol.14, pp.15-25, 2003.
67. C. Acar, and A. Shkel. Experimental Evaluation and Comparative Analysis of Commercial Variable-Capacitance MEMS Accelerometers. *Journal of Micromechanics and Microengineering*. Vol.13, pp.634-645, 2003.
68. C. Acar, and A. Shkel. Four Degrees-of-Freedom Micromachined Gyroscopes. *Journal of Modeling and Simulation of Microsystems*, Vol. 2, No. 1, pp. 71-82, 2001.
69. C. Acar, A. Shkel. Non-Resonant Micromachined Gyroscopes with Structural Mode-Decoupling. *IEEE Sensors Journal*, Vol. 3, No. 4, pp. 497-506, 2003.
70. US Patent 7,377,167. Cenk Acar and Andrei Shkel. Non-resonant micromachined gyroscopes with structural mode-decoupling.
71. US Patent 7,284,430. Cenk Acar and Andrei Shkel. Robust micromachined gyroscopes with two degrees of freedom sense-mode oscillator.
72. US Patent 7,279,761. Cenk Acar and Andrei Shkel. Post-release capacitance enhancement in micromachined devices and a method of performing the same.
73. US Patent 7,100,446. Cenk Acar and Andrei Shkel. Distributed-mass micromachined gyroscopes operated with drive-mode bandwidth enhancement.
74. US Patent 6,845,669. Cenk Acar and Andrei Shkel. Non-resonant four degrees-of-freedom micromachined gyroscope.
75. Cenk Acar, Adam Schofield, Andrei Shkel, Lynn Costlow, Asad Madni. Robust Six Degree-of-Freedom Micromachined Gyroscope with Anti-Phase Drive Scheme Patent Pending, UC Office of Technology Transfer.
76. C. Acar and A. Shkel. Torsional z-Axis Surface-Micromachined Gyroscopes with Non-Resonant Actuation. *Patent pending, UC Office of Technology Transfer*.
77. C. Acar, A. M. Shkel, L. Costlow, and A. M. Madni, "Inherently robust micromachined gyroscopes with 2-DOF sense-mode oscillator," in *Proc. of IEEE Sensors*, Irvine, CA, USA, Oct. 31- Nov. 3, 2005, pp. 664-667.
78. C. Acar, A. Shkel. Enhancement of Drive-Mode Bandwidth in MEMS Vibratory Gyroscopes Utilizing Multiple Oscillators. *Solid-State Sensor and Actuator Workshop, Hilton Head Island, SC, June 2004*.
79. C. Acar, A. Shkel. A Design Approach for Robustness Improvement of Rate Gyroscopes. *Modeling and Simulation of Microsystems Conference*, March 2001.
80. C. Acar, A. Shkel. Microgyroscopes with Dynamic Disturbance Rejection. *SPIE Conference on Smart Electronics and MEMS*, March 2001.
81. C. Acar, S. Eler, and A. Shkel. Concept, Implementation, and Control of Wide Bandwidth MEMS Gyroscopes. *American Control Conference*, June 2001.

82. C. Acar, A. Shkel. Design Concept and Preliminary Experimental Demonstration of MEMS Gyroscopes with 4-DOF "Master-Slave" Architecture. *SPIE Conference on Smart Electronics and MEMS*, March 2002.
83. C. Acar, and A. Shkel. A Class of MEMS Gyroscopes with Increased Parametric Space. *Proceedings of IEEE Sensors Conference*, Orlando, Florida, 2002, pp. 854-859.
84. C. Acar, A. Shkel. Distributed-Mass Micromachined Gyroscopes for Enhanced Mode-Decoupling. *IEEE Sensors Conference, September 2003, Toronto, Canada*.
85. J.A. Geen. A Path to Low Cost Gyroscopy. *Solid-State Sensor and Actuator Workshop*, Hilton-Head, SJ, 1998, pp. 51-54.
86. W. Geiger, W.U. Butt, A. Gaisser, J. Fretch, M. Braxmaier, T. Link, A. Kohne, P. Nommensen, H. Sandmaier, and W. Lang. Decoupled Microgyros and the Design Principle DAVED. *IEEE Sensors Journal*, 2001, pp. 170-173.
87. Y. Mochida, M. Tamura, and K. Ohwada. A Micromachined Vibrating Rate Gyroscope with Independent Beams for Drive and Detection Modes. *Sensors and Actuators A*, Vol. 80, 2000, pp. 170-178.
88. M. Niu, W. Xue, X. Wang, J. Xie, G. Yang, and W. Wang. Design and Characteristics of Two-Gimbals Micro-Gyroscopes Fabricated with Quasi-LIGA Process. *International Conference on Solid-State Sensor and Actuators*, 1997, pp. 891-894.
89. U. Breng, W. Guttman, P. Leinfelder, B. Ryrko, S. Zimmermann, D. Billep, T. Gessner, K. Hillner, and M. Weimer. A Bulk Micromachined Gyroscope Based on Coupled Resonators. *International Conference on Solid-State Sensor and Actuators*, Japan, 1999, pp. 1570-1573.
90. H.T. Lim, J.W. Song, J.G. Lee, and Y.K. Kim. A Few deg/hr Resolvable Low Noise Lateral Microgyroscope. *Proceedings of IEEE MEMS Conference, NV*, 2002, pp. 627-630.
91. S.E. Alper, and T. Akin. A Symmetric Surface Micromachined Gyroscope with Decoupled Oscillation Modes. *Sensors and Actuators A*, Vol. 97, 2002, pp. 347-358.
92. Y.S. Hong, J.H. Lee, and S.H. Kim. A Laterally Driven Symmetric Micro-Resonator for Gyroscopic Applications. *Journal of Micromechanics and Microengineering*, Vol. 10, 2000, pp. 452-458.
93. C.W. Dyck, J. Allen, R. Hueber. Parallel Plate Electrostatic Dual Mass Oscillator. *Proceedings of SPIE Conference on Micromachining and Microfabrication, Vol. 3876, CA*, 1999, pp. 198-209.
94. US 6,691,571. Willig et al. Rotational Speed Sensor. February 2004.
95. Funk, K. Emmerich, H. Schilp, A. Offenber, M. Neul, R. Larmer, F. A Surface Micromachined Silicon Gyroscope Using a Thick Polysilicon Layer. *Twelfth IEEE International Conference on Micro Electro Mechanical Systems*, 1999, pp. 57-60.
96. J. J. Wortman and R. A. Evans. Young's Modulus, Shear Modulus, and Poisson's Ratio in Silicon and Germanium. *Journal of Applied Physics*, 1965. 36, 153.
97. Kuisma, H.; Ryhanen, T.; Lahdenpera, J.; Punkka, E.; Ruotsalainen, S.; Sillanpaa, T.; Seppa, H.. A Bulk Micromachined Silicon Angular Rate Sensor *International Conference on Solid State Sensors and Actuators, 1997*. Volume 2, Chicago 16-19 Jun 1997 pp. 875 - 878
98. S. V. Iyer, Y. Zhou and T. Mukherjee. Analytical Modeling of Cross-axis Coupling in Micromechanical Springs *International Conference on Modeling and Simulation of Microsystems (MSM)*. pp. 632-635, April 19-21, 1999, San Juan, PR, USA.
99. Geiger, W.; Folkmer, B.; Merz, J.; Sandmaier, H.; Lang, W.. A New Silicon Rate Gyroscope *The Eleventh Annual International Workshop on Micro Electro Mechanical Systems, 1998*. 25-29 Jan 1998 pp. 615 - 620
100. S. Gnthner, K. Kapser, M. Rose, B. Hartmann, M. Kluge, U. Schmid, and H. Seidel. Analysis of Piezoresistive Read-out Signals for a Silicon Tuning Fork Gyroscope *IEEE Sensors Conference, 2004*. Vienna, Austria, Oct. 2004, pp. 1411-1414.
101. Weinberg, M.S.; Kourepenis, A. Error sources in in-plane silicon tuning-fork MEMS gyroscopes *Journal of Microelectromechanical Systems*. Volume 15, Issue 3, June 2006, pp. 479 - 491.
102. A. Duwel, M. Weinstein, J. Gorman, J. Borenstein, P. Ward. Quality Factors of MEMS Gyros and the Role of Thermoelastic Damping *International Conference on Micro Electro Mechanical Systems, 2002*. Las Vegas, NV, January 2002, pp. 214-219.

103. C. Zener. Internal Friction in Solids II. General Theory of Thermoelastic Internal Friction. *Physical Review*, 1938. Vol. 53, pp. 90-99.
104. W. C. Tang. Electrostatic Comb-Drive for Resonant Sensor and Actuator Applications. *Ph.D. Thesis, University of California at Berkeley*, 1990.
105. B.E. Boser. Electronics For Micromachined Inertial Sensors. *Proceedings of Transducers*, 1997.
106. W.C. Young. Roark's Formulas for Stress and Strain. *McGraw-Hill, Inc.*, pp. 93-156, 1989.
107. M.J. Madou. Fundamentals of Microfabrication: The Science of Miniaturization. *CRC Press.*, Second Edition, 2002.
108. W. Kuehnel. Modeling of the Mechanical Behavior of a Differential Capacitor Acceleration Sensor. *Sensors and Actuators A*, Vol. 48, 1995, pp. 101-108.
109. T. Veijola, and M. Turowski. Compact Damping Models for Laterally Moving Microstructures with Gas-Rarefaction Effects. *Journal of Microelectromechanical Systems*, Vol. 10, No.2, June 2001, pp. 263-273.
110. T. Veijola, H. Kuisma, J. Lahdenpera and T. Ryhenen. Equivalent Circuit Model of the Squeezed Gas Film in a Silicon Accelerator. *Sensors and Actuators A*, Vol. 48, 1995, pp. 239-248.
111. J.J. Blech. On Isothermal Squeeze Films. *Journal of Lubrication Technology*, Vol. 105, 1983, pp. 615-620.
112. Y.H. Cho, B.M. Kwak, A.P. Pisano, and R.T. Howe. Slide Film Damping in Laterally Driven Microstructures. *Sensors and Actuators A*, Vol. 40, 1994, pp. 31-39.
113. C. Bourgeois, F. Parret, and A. Hoogerwerf. Analytical Modeling of Squeeze-Film Damping in Accelerometers. *International Conference on Solid-State Sensors and Actuators*, Chicago, IL, June 1997, pp. 1117-1120.
114. <http://www.analogdevices.com>.
115. T.N. Juneau, A.P. Pisano, J.H. Smith. Dual Axis Operation of a Micromachined Rate Gyroscope. *Ninth International Conference on Solid-State Sensors and Actuators*, Chicago, IL, June 1997.
116. S.E. Alper, and T. Akin. A Planar Gyroscope Using Standard Surface Micromachining Process. *Conference on Solid-State Transducers*, Copenhagen, Denmark, 2000, pp. 387-390.
117. <http://www.sensofar.com>.
118. <http://www.saesgetters.com>.
119. <http://www.polytecpi.com>.
120. <http://www.mmr.com/ltmpd.htm>
121. M. Handtmann, R. Aigner, A. Meckes, and G.K.M. Wachutka. A Sensitivity Enhancement of MEMS Inertial Sensors Using Negative Springs and Active Control. *Sensors and Actuators A*, Vol. 97, 2002, pp. 153-160.
122. A. Lawrence. Modern Inertial Technology. *Springer*, 1998.
123. T. Hirano, T. Furuhashi, K.J. Gabriel, and H. Fujita. Design, Fabrication and Operation of Submicron Gap Comb-Drive Microactuators. *Journal of Microelectromechanical Systems*, Vol. 1, 1992, pp. 52-59.
124. F. Ayazi, and K. Najafi. High Aspect-Ratio Combined Poly and Single-Crystal Silicon (HARPSS) MEMS Technology *Journal of Microelectromechanical Systems*, Vol. 9, 2000, pp. 288-294.
125. S. Pourkamali, F. Ayazi. SOI-Based HF and VHF Single-Crystal Silicon Resonators With Sub-100 Nanometer Vertical Capacitive Gaps. *Proceedings of Solid-State Sensor and Actuator Workshop*, 2003, pp. 837-840.
126. <http://www.microsensors.com>
127. <http://www.mems-exchange.org>
128. <http://www.suss.com>
129. Smith, J.H.; Montague, S.; Sniegowski, J.J.; Murray, J.R.; McWhorter, P.J. Embedded micromechanical devices for the monolithic integration of MEMS with CMOS. *International Electron Devices Meeting*, 1995., pp.609-612, 10-13 Dec 1995.

130. T. A. Core, W. K. Tsang, and S. J. Sherman. Fabrication technology for an integrated surface-micromachined sensor. *Solid State Technology*, vol. 36, no. 10, pp. 3940, 42, 44, 4647, Oct. 1993.
131. K. Y. Park, C. W. Lee, Y. S. Oh, and Y. H. Cho. Laterally oscillated and force-balanced micro vibratory rate gyroscope supported by fish-hook shape springs. *Proc. IEEE Micro Electro Mechanical Systems Workshop (MEMS97)*, Japan, 1997, pp. 494499.
132. W. C. Tang, C.T.-C. Nguyen, M. W. Judy, and R. T. Howe. Electrostatic-comb drive of lateral polysilicon resonators. *Sensors and Actuators*, vol. A21-23, 1990, pp. 328-331.
133. C.T.-C. Nguyen. Micromachined Signal Processors. *Ph.D. Thesis, University of California, Berkeley*, 1994.
134. Laermer, F.; Urban, A.. Milestones in deep reactive ion etching. *International Conference on Solid State Sensors and Actuators Transducers '05*, Volume 2, pp. 1118-1121, 2005.
135. Lutz, M.; Golderer, W.; Gerstenmeier, J.; Marek, J.; Maihofer, B.; Mahler, S.; Munzel, H.; Bischof, U. A precision yaw rate sensor in silicon micromachining. *International Conference on Solid State Sensors and Actuators Transducers '97 Chicago*, Volume 2, pp. 847 - 850, 1997.
136. R.N. Candler, W.T. Park, H.M. Li, G. Yama, A. Partridge, M. Lutz, and T.W. Kenny. Single Wafer Encapsulation of MEMS Devices. *IEEE Trans. Advanced Packaging*, 26, 227, 2003.
137. Y. Dong, M. Kraft and W. Redman-White. Micromachined vibratory gyroscopes controlled by a high order band-pass sigma delta modulator. *IEEE Sensors Journal*, 7 (1). pp. 59-69, 2007.
138. Y. Dong, M. Kraft and W. Redman-White. High Order Bandpass Sigma Delta Interface for Vibratory Gyroscopes. *2005 IEEE Sensors Conference*, pp. 1080 - 1083, 2005
139. Rodjegard, H. Sandstrom, D. Pelin, P. Hedenstierna, N. Eckerbert, D. Andersson, G.I. A digitally controlled MEMS gyroscope with 3.2 deg/hr stability. *Solid-State Sensors, Actuators and Microsystems, Transducers 2005*, Vol 1, pp. 535- 538, 2005.
140. A. Madni and L. Costlow, "A third generation, highly monitored, micromachined quartz rate sensor for safety-critical vehicle stability control," in *Proc. Aerospace Conference IEEE*, vol. 5, 2001, pp. 2523-2534.
141. A. Madni, L. Costlow, and S. Knowles, "Common design techniques for BEI GyroChip quartz rate sensors for both automotive and aerospace/defense markets," *IEEE Sensors J.*, vol. 3, no. 5, pp. 569-578, 2003.
142. M. Weinberg and A. Kourepenis, "Error sources in in-plane silicon tuning-fork MEMS gyroscopes," *J. Microelectromech. Syst.*, vol. 15, no. 3, pp. 479-491, Jun. 2006.
143. U.-M. Gomez, B. Kuhlmann, J. Classen, W. Bauer, C. Lang, M. Veith, E. Esch, J. Frey, F. Grabmaier, K. Offterdinger, T. Raab, H.-J. Faisst, R. Willig, and R. Neul, "New surface micromachined angular rate sensor for vehicle stabilizing systems in automotive applications," in *Proc. of International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS '05)*, vol. 1, 2005, pp. 184-187.
144. R. Neul, U. Gomez, K. Kehr, W. Bauer, J. Classen, C. Doring, E. Esch, S. Gotz, J. Hauer, B. Kuhlmann, C. Lang, M. Veith, and R. Willig, "Micromachined gyros for automotive applications," in *Proc. IEEE Sensors*, 2005.
145. R. Neul, U.-M. Gomez, K. Kehr, W. Bauer, J. Classen, C. Doring, E. Esch, S. Gotz, J. Hauer, B. Kuhlmann, C. Lang, M. Veith, and R. Willig, "Micromachined angular rate sensors for automotive applications," *IEEE Sensors J.*, vol. 7, no. 2, pp. 302-309, Feb. 2007.
146. J. Geen, "Progress in integrated gyroscopes," in *Proc. Position Location and Navigation Symposium (PLANS 2004)*, 2004, pp. 1-6.
147. J. Geen, "Very low cost gyroscopes," in *Proc. IEEE Sensors*, 2005.
148. J. A. Geen, S. J. Sherman, J. F. Chang, and S. R. Lewis, "Single-chip surface micromachined integrated gyroscope with 50 deg/h allan deviation," *IEEE J. Solid-State Circuits*, vol. 37, no. 12, pp. 1860-1866, Dec. 2002.
149. A. R. Schofield, A. A. Trusov, C. Acar, and A. M. Shkel, "Anti-phase driven rate gyroscope with multi-degree of freedom sense mode," in *Proc. International Solid-State Sensors, Actuators and Microsystems Conference, TRANSDUCERS 2007*, Lyon, France, Jun. 10-14, 2007, pp. 1199-1202.

150. A. R. Schofield, A. A. Trusov, and A. M. Shkel, "Multi-degree of freedom tuning fork gyroscope demonstrating shock rejection," in *Proc. IEEE Sensors*, Atlanta, GA, USA, Oct. 28–31, 2007, pp. 120–123.
151. A. A. Trusov, A. R. Schofield, and A. M. Shkel, "New architectural design of a temperature robust MEMS gyroscope with improved gain-bandwidth characteristics," Hilton Head Workshop in Solid State Sensors, Actuators, and Microsystems, Jun. 1–5, 2008.
152. M. S. Kranz and G. K. Fedder, "Micromechanical vibratory rate gyroscope fabricated in conventional CMOS," in *Symposium Gyro Technology*, Stuttgart, Germany, Sep. 16–17, 1997, pp. 3.0–3.8.
153. S. Alper and T. Akin, "A single-crystal silicon symmetrical and decoupled MEMS gyroscope on an insulating substrate," *J. Microelectromech. Syst.*, vol. 14, no. 4, pp. 707–717, Aug. 2005.
154. J. G. L. Woon-Tahk Sung, Sangkyung Sung and T. Kang, "Design and performance test of a MEMS vibratory gyroscope with a novel AGC force rebalance control," *J. Micromech. Microeng.*, vol. 17, no. 10, pp. 1939–1948, Oct. 2007.
155. S. Alper, K. Azgin, and T. Akin, "A high-performance silicon-on-insulator MEMS gyroscope operating at atmospheric pressure," *Sensors and Actuators A: Physical*, vol. 135, no. 1, pp. 34–42, Mar. 2006.

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