Journal of Theoretical and Applied Information Technology
10th April 2013. Vol. 50 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

A NOVEL NON-FLOATING THERMAL CONVECTION ANGULAR ACCELEROMETER AND INTEGRATED WITH RFID TAG

[1]JIUM-MING LIN, [2] CHENG-HUNG LIN

[1] Dept. of Communication Engineering Chung-Hua University Hsin-Chu 30012, Taiwan, ROC
[2] Ph. D. Program in Engineering Science College of Engineering, Chung-Hua University Hsin-Chu 30012, Taiwan, ROC
E-mail: [1]jmlin@chu.edu.tw, [2]b09306014@chu.edu.tw

ABSTRACT

In this paper five new ideas are proposed to integrate both an active RFID tag with a non-floating type thermal convection angular accelerometers on a flexible substrate, thus the device becomes a wireless sensor. The most innovative idea is to make it directly on the substrate without creating the grooved chamber of a traditional thermal convection accelerometer, and the device doesn't use any movable parts, so it is very reliable and easy to make. The second new idea is to apply the engineering plastic such as polyimide, so the thermal conductivity of the new device substrate is much lower than silicon, and it can save much power and very useful in various fields. The third new idea is to use Xe gas in the chamber instead of the previous CO_2; the latter can produce oxidation effect to the heater and thermal sensors, while Xe gas will not, so the heater and sensor reliability and life cycle can be increased. Trade-off study for the temperature sensor locations is also made. The sensitivity of the new device is 273℃/(rad/s^2).

Keywords: *Angular Accelerometer, RFID Tag, Flexible Substrate, Thermal Convection, Hemispherical Chamber, Xenon Gas, Carbon Dioxide*

1. INTRODUCTION

Many accelerometers are made on silicon wafers [1-4], some methods used the thermal convection technologies and filling the chamber with air, CO_2, liquid, or others. In this paper five new ideas are proposed to integrate an active RFID tag with a thermal convection angular accelerometers on a flexible substrate as in Fig. 1, thus it becomes a more powerful wireless angular accelerometer. The first new idea is that this device is made directly on the substrate with neither the traditional grooved chamber of a thermal convection accelerometer nor movable parts, so it is very easy to make and the reliability is very good. The second new idea is to use plastic or polyimide substrate, since the plastic thermal conductivity (0.06-0.0017W/(cm-K)) is about twenty-fifth of the silicon (1.48W/(cm-K)), thus it can save both power and cost of the power leakage through the substrate for long time operation. The third new idea is to fill Xe gas in the chamber instead of the previous CO_2; the latter can produce oxidation effect to the heater and thermal sensors [5-21], while Xe gas will not, so the heater and sensor reliability and life cycle can be increased. Besides, the Xe molecular weight (131.29 g/mol) is three times of CO_2 (44.01 g/mol), so the new device can give quicker time response. The fourth new is to apply a hemispherical chamber as shown in Fig. 2; it is more streamline in nature with less drag effect, so the bandwidth is larger than the previous one by using rectangular chamber. The fifth new idea and the most powerful one is to integrate an active RFID tag with a thermal convection angular accelerometer on the same substrate, thus the new device becomes a more useful wireless angular accelerometer, one can apply it in the fields of hospital monitoring, game, etc., so it is very easy to make and use. The heater is made of chromium and nickel by using E-gun evaporation, its operating temperature is 127°C and without melting the polyimide substrate. Two temperature sensors (poly-silicon doped with boron) on both sides of heaters are made by E-gun. Trade-off study for the temperature sensor locations is also made. The sensitivity of the new device is 273℃/(rad/s2). The paper organization is asfollows: the first section is introduction. The next concerns fabrication and packaging steps. The third one is simulation and discussion. The summary is given in the last section.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

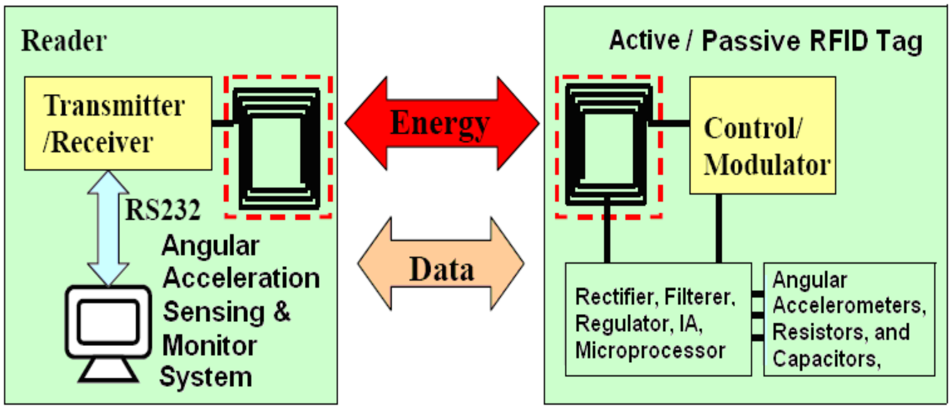

Fig.1 Block Diagram Of The Angular Accelerometer.

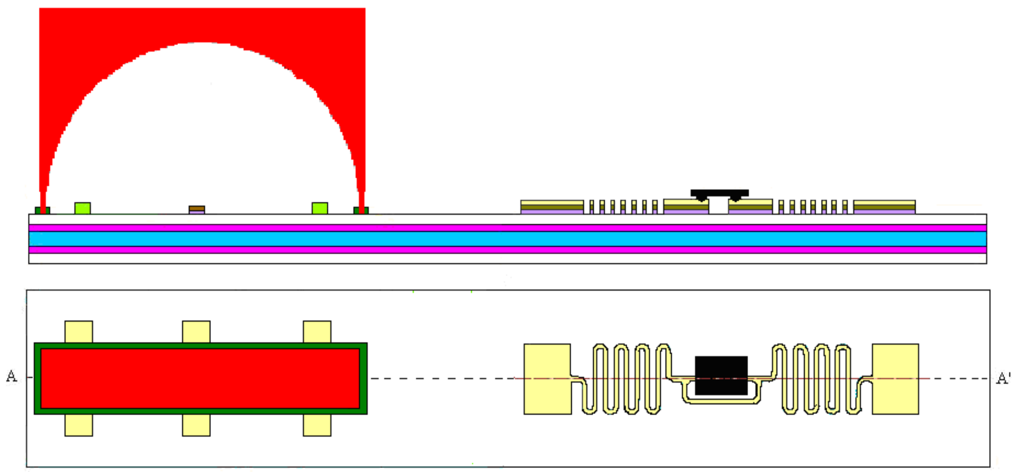

Fig.2 Side-View Of The Angular Accelerometer.

2. FABRICATION AND PACKAGING STEPS

Step 1: E-gun evaporates SiO_2 on both surfaces for thermal, electrical and humidity isolation, then cover Photo Resist (PR) to protect SiO_2. Deposit a layer of p-type amorphous silicon (100-250μm), use an Nd-YAG laser to anneal it as a poly-silicon. The next is to use mask #1 and PAEP to reserve the PR on the poly-silicon thermister. Then remove the layers of poly-silicon without PR protection. Finally, remove the PR, the result is in Fig. 3.

Step 2: Deposit Cr and Ni to make heater, RFID antenna, and the conductors connected to the power

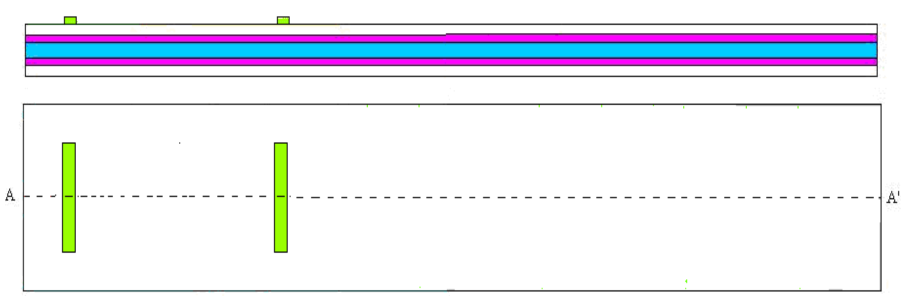

Fig.3 Result Of Step 1.

Journal of Theoretical and Applied Information Technology
10th April 2013. Vol. 50 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

supply. The next is to use mask#2 and PAEP to reserve the PR on the heater, RFID antenna, and the conductors connected to the power supply. Then remove Cr and Ni without PR protection. After remove the PR, the result is in Fig. 4.

Step 3: Use mask #3 and PAEP to reserve PR on heater, and electroless-plating gold on Ni to raise the conductivity of antenna, and the conductors connected to power supply. Besides, the pads wettability and soldering performance can also be increased. Remove the PR, the result is in Fig. 5.

Step 4: Print plastic sealing material around the angular accelerometer as dam bar as in Fig. 6.

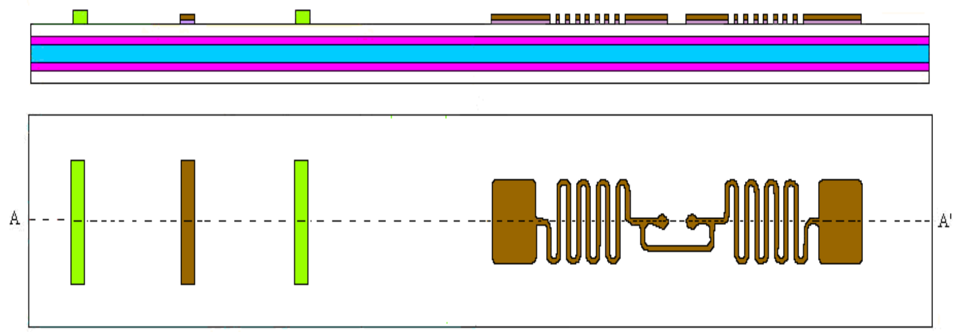

Fig.4 Result Of Step 2.

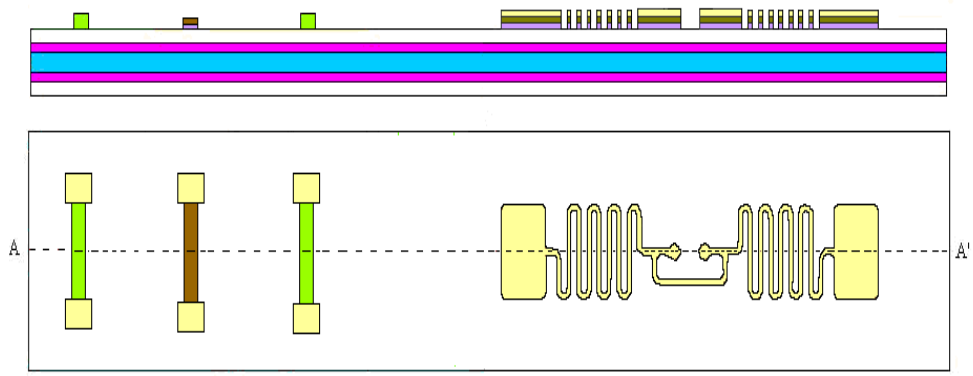

Fig.5 Result Of Step 3.

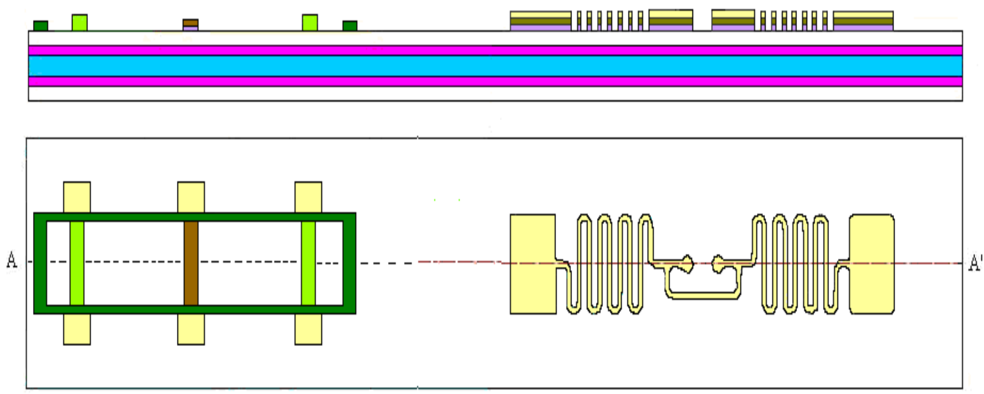

Fig.6 Result Of Step 4.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Step 5: Flip-chip bond the bumped RFID chip to antenna feed terminals by thermal compression, make the underfill to increase RFID chip adherence. Put a cap with hemi-spherical chamber on the dam bar, then curing and make it vacuum. Finally, fill with xenon gas. The result is as in Fig. 2.

3. SIMULATION AND DISCUSSION

Firstly, the chamber and sensor geometric dimensions are defined in Fig. 7. We will trade-off the thermal sensors location at the indicated three points. The temperatures of the package boundaries and the heaters are set respectively as 300K and 400K. The ESI-CFD+ governing equations for the conservation of mass, momentum, and energy are as:

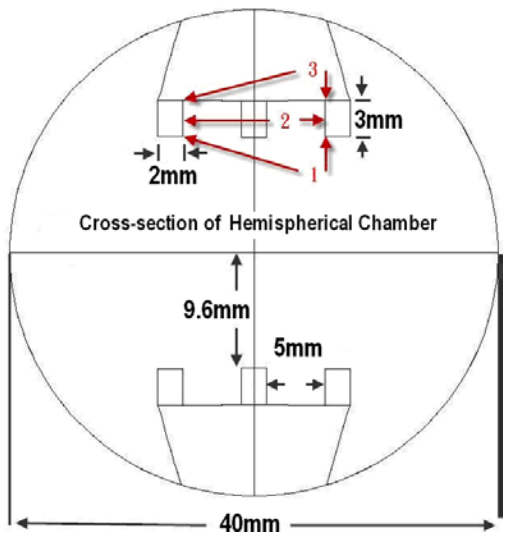

Fig.7 Geometric Dimension Of Chamber, Heater And Sensors.

$$\nabla \cdot \bar{u} = 0 \quad \textbf{(1)}$$

$$\frac{\partial \rho}{\partial t} + \nabla \rho \bar{u} = 0 \quad \textbf{(2)}$$

$$\frac{\partial \rho \bar{u}}{\partial t} + \nabla(\rho \overline{uu}) = \rho\beta(T - T_{heater})\alpha \quad \textbf{(3)}$$

$$\rho c_P \bar{u} \nabla T = k \nabla^2 T \quad \textbf{(4)}$$

$$\rho = \frac{p}{RT} \quad \textbf{(5)}$$

In the above equations, u is the velocity vector, t is the time, and ρ, μ_m, p, and a are respectively the density, dynamic viscosity, pressure, and acceleration. c_p, T, R and k are respectively the fluid specific heat, temperature, ideal gas constant and thermal conductivity. Then the sensitivity curves of the sensors located at points 1-3 are as shown in Fig. 8. Note the sensitivity at point 1 is the better one. Fig. 9 shows the gas flow distributions in both vertical and horizontal planes at point 1 for several values of angular acceleration. Note the gas flow field can touch point 1 only for angular acceleration larger than 0.09301 rad/s^2. This is the reason why the sensitivities at points 2 and 3 are less than that at point 1 as shown in Fig. 8. To increase the sensitivities of the sensors for the geometric dimensions in Fig. 8, we increase the length of the sensors and reduce the separation distance of sensors and heater as in Fig. 10. Fig. 11 shows the sensitivity curves of the new sensors in Fig. 10. Now the sensitivity for the sensors located at point 2 is also the better one, and it is much larger than the previous ones as in Fig. 8. Fig. 12 shows the gas flow distributions in both vertical and horizontal planes at new point 2 for several angular accelerations. Note the gas flow field can always touch the temperature sensors. Thus the length of the temperature sensors cannot be too short, and the separation distance of sensors and heater cannot be too long. The sensitivity of the new device is 273°C/(rad/s^2).

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

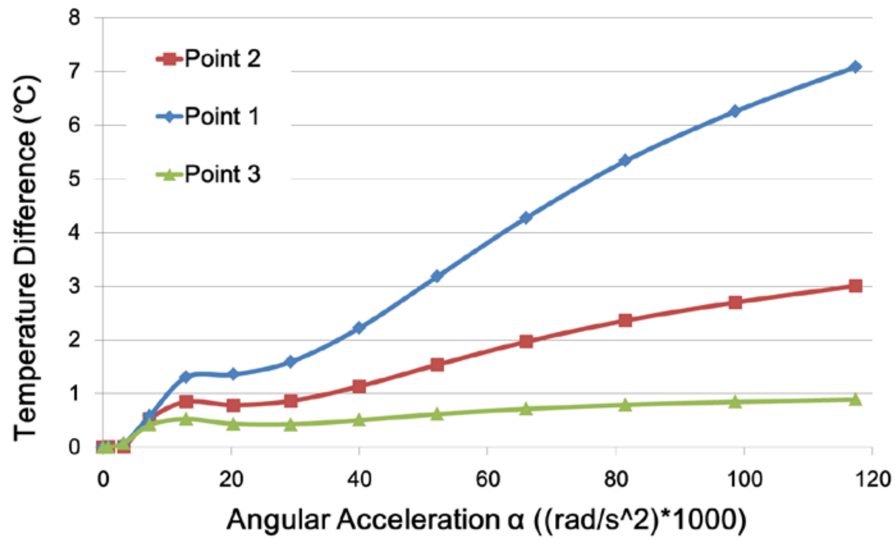

Fig.8 Sensitivity Curves Of Sensors In Fig. 7.

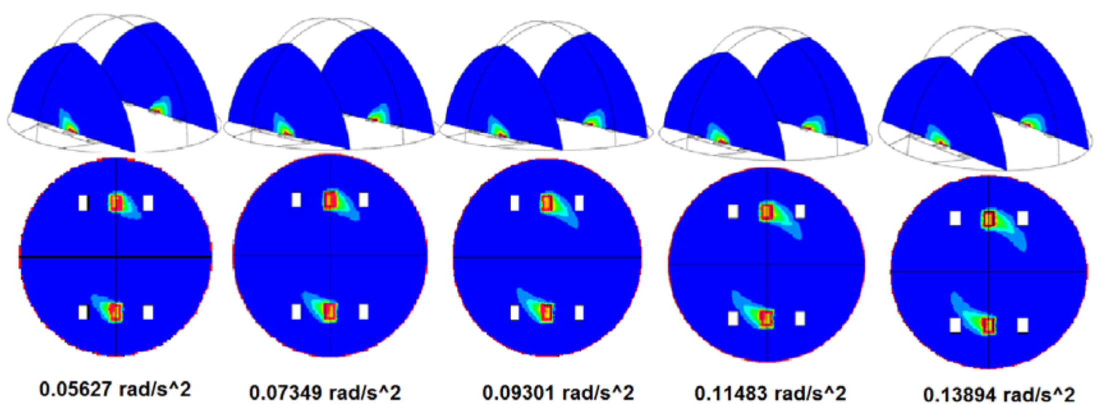

Fig.9 Gas Flow Distributions In Both Vertical And Horizontal Planes For Sensors Located At Points 1 In Fig. 7.

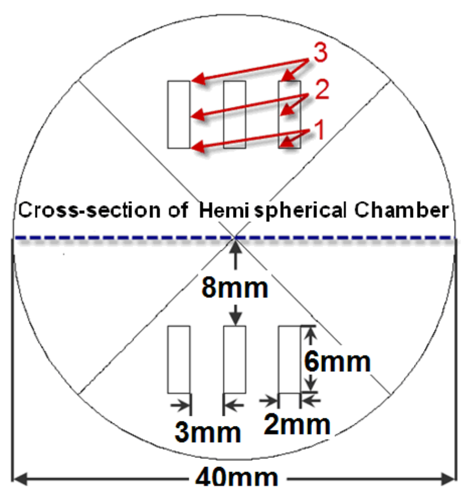

Fig.10 New Sensor Geometric Dimensions.

Journal of Theoretical and Applied Information Technology
10th April 2013. Vol. 50 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

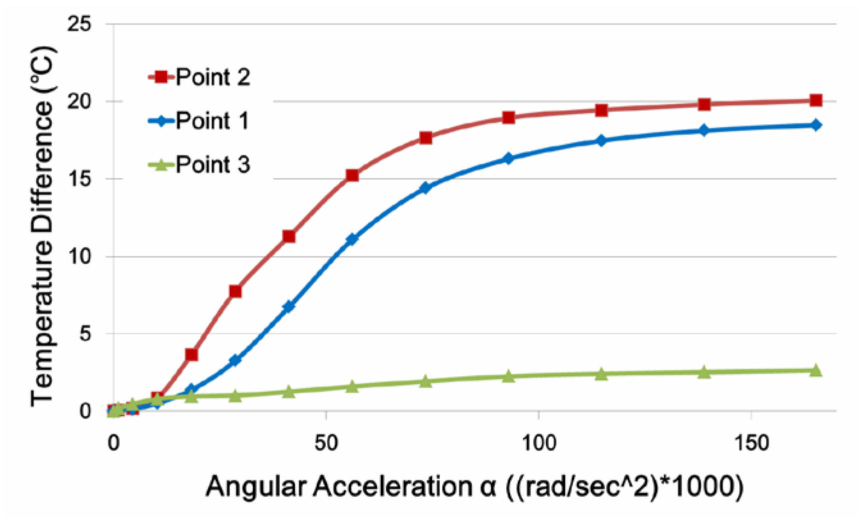

Fig.11 Sensitivity Curves Of Sensors In Fig. 10.

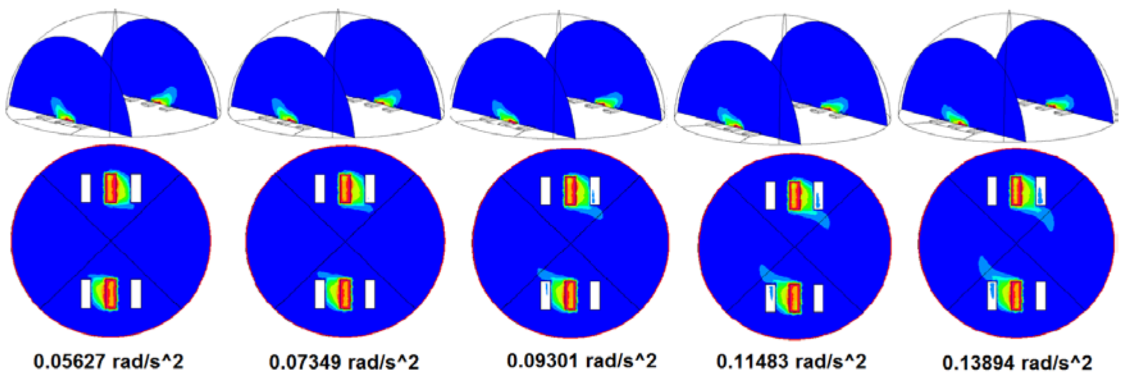

Fig.12 Gas Flow Distributions In Both Vertical And Horizontal Planes For Sensors Located At New Points 2.

4. CONCLUSIONS

The process of In this paper a novel non-floating type thermal convection angular accelerometer is integrated with an active RFID tag on a flexible substrate, thus the device becomes a wireless sensor. The most innovative idea is that this device is made directly on the substrate without the traditional grooved chamber of a thermal convection accelerometer; it is also without any movable parts, so the device is very reliable and easy to make. The second new idea is to apply the plastic substrate, the thermal conductivity of the substrate is much lower than silicon, and then it can save more power and very useful in various fields. Trade-off study for the length and location of the temperature sensors are also made. Note the length of the temperature sensors cannot be too short, and the separation distance of sensors and heater cannot be too long. Otherwise, the sensitivity would be too small. The sensitivity of the new device is 273°C(rad/s^2).

5. ACKNOWLEDGMENT

This research was supported by National Science Council with the grants: NSC 101-2622-E-216-001-CC3, 101-2221-E-216-006-MY2, 101-2221-E-216-019-, and National Center for High-performance Computing (NCHC) for computer time and facilities of ESI-CFD+ software package.

REFRENCES:

[1] L. Lin, R.T. Howe, and A.P. Pisano, “Microelectromechanical filters for signal processing,” J. Micro-Electromechanical System, vol. 7, pp. 286–294, September 1998.

[2] Y. Zhao, A. Leung, M.E. Rebeschini, G.P. Pucci, Dribinsky, and B.A.Y. Cai, “Method and

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

circuitry for thermal accelerometer signal conditioning," U.S. Patent 7,305,881, December 2007.

[3] K.M. Liao, R. Chen, and B.C.S. Chou, "Design of a thermal-bubble-based micromachined accelerometer," Proceedings of 2005 International Conference on MEMS, NANO and Smart Systems, pp. 438–442, July 2005.

[4] V. Milanovic, E. Bowen, N. Tea, J.S. Suehle, B. Payne, M.E. Zaghloul, and M. Gaitan, "Convection-based accelerometer and tilted sensor implemented in standard CMOS," *Proceedings of International Mechanical Engineering Conference and Exposition, MEMS Symposia. Ca*, November 1998, pp.1-4.

[5] X.B. Luo, Z.X Li, Z.Y. Guo, and Y.J. Yang, "An optimized micromachined convective accelerometer with no proof mass," *Journal of Micromechanics and Microengineering*, Vol. 11, July 2001, pp. 504-508.

[6] L. Lin, A.P. Pisano, and V.P. Carey, "Thermal bubble powered microactuators, " *Microsystem Technologies*, Vol. 1, 1994, pp. 51-58.

[7] J.H. Tsai and L. Lin, "Active microfluidic mixer and gas bubble filter driven by thermal bubble micropump, " *Sensors and Actuators A: Physical*, Vol. 97, 2002, pp. 665-671.

[8] J. Dido, P. Loisel, and A. Renault, "Thermal accelerometer with automatic zero control," *U.S. Patent 7,426,862*,. September 2008.

[9] R.J. Naumann, G. Haulenbeek, H. Kawamura, and K. Matsunaga, "The JUSTSAP experiment on STS-95," *Microgravity Science and Technology*, Vol. 13, 2002, pp.22-32.

[10] S.W. Arms and C.P. Townsend, "MEMS based angular accelerometer," *U.S. Patent 2003/0047002 A1*,. March 2003.

[11] F. Peluso, D. Castagnolo, and C. Albanese, "A naive accelerometer acting in the continuum range," *Microgravity Sci. Technol*, Vol. 13, 2002, pp. 41-52.

[12] G. Piazza and P. Stephanou, "Micromechanical thermo-fluidic single-axis yaw rate sensor", *University of California Berkeley*, 2002.

[13] Garraud, A. Giani, P. Combette, B. Charlot, and M. Richard, "A dual axis CMOS micromachined convective thermal accelerometer,“ *Sensors and Actuators A: Physical*, Vol. 170, 2011, pp.44-50.

[14] F. Khoshnoud and C.W. de Silva, "IEEE Recent advances in MEMS sensor technology-mechanical applications," *Instrumentation & Measurement Magazine*, Vol. 15, pp.14-24, 2012.

[15] G.P. Dribinsky, Y. Pucci, M. Cai, G.J. Varghese, O'Brien, Y. Zhao and Y.Y. Cai, "Temperature-gradient cancellation technique and device," *U.S. Patent 7,862,229 B2*,. Janeraary 2011.

[16] R. Alain, V. Alain, Bernard, and G. Alain, "Thermal accelerometer with reduced sensitivity to an external magnetic field," *European Patent EP1550874*, Janeraary 2010.

[17] A. Rekik, B. Mezghani, F. Azaïs, N. Dumas, M. Masmoudi, F. Mailly, and P. Nouet, "From 2D to 3D FEM simulations of a CMOS MEMS convective accelerometer," *2011 Symp. on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP)*, December 2011, pp. 1-5.

[18] A. Rekik, F. Azaïs, N. Dumas, F. Mailly, and P. Nouet, "A behavioral model of MEMS convective accelerometers for the evaluation of design and calibration strategies at system level," *Journal of Electronic Testing*, Vol. 27, 2011, pp. 411-423.

[19] F. Azaïs, N. Dumas, F. Mailly, and P. Nouet, "Modeling the influence of etching defects on the sensitivity of MEMS convective accelerometers," *2011 IEEE 17th International Mixed-Signals, Sensors and Systems Test Workshop (IMS3TW)* , 2011, pp.1-6.

[20] J. Ma, X. Yan, D. Chu, and Y. He, "Online driving states monitoring using fusion of multi-sensor information," *Journal of Theoretical and Applied Information Technology*, Vol. 46, 2012, pp. 274-283.

[21] W. Chen, W. li, and X. Zhang, "Mobile robot-based virtual V-BLAST MIMO transmission scheme in distributed wireless sensor networks," *Journal of Theoretical and Applied Information Technology*, Vol. 46, 2012, pp. 677-685.