GALLIUM ARSENIDE BASED MICROSENSOR SYSTEMS

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Abstract - Gallium Arsenide (GaAs) based microsensors, analog readout electronics, analog to digital converters and digital signal processors have been in development. Microsensors include accelerometers, infrared sensors, and micromachines with high speed sensing response, extreme temperature operation, and high radiation hardness.

I. INTRODUCTION

GaAs microsensors have potentially significant future applications in the areas of 1) high speed sensor systems, 2) extreme temperature environments, 3) applications requiring radiation hardness, and 4) systems requiring high-performance multi-functionality such as those containing electronics, physical sensors and micro-optics. The combination of sensors and circuits on a single substrate (commonly called *integrated microsensors* and *microelectromechanical systems* or *MEMS*) represents an attractive approach in being able to realize compact systems as described above with minimal parasitic interconnection losses. Top-Vu Technology has been developing gallium arsenide (GaAs) based microsensor systems. These GaAs microsystems include microsensors, analog readout electronics, analog to digital converters and digital signal processors [1-9].

II. PROCESS DESIGN AND FABRICATION

The technical approach in the areas of microsensor technology, piezoelectric and pyroelectric materials, and solid-state micromachining is to extend sensor micromachining methods to allow the compatible integration of on-chip GaAs electronics. A representative cross section of a GaAs-based microaccelerometer is shown in Fig. 1.

A. *Ferroelectric Materials*

In a typical sol-gel process, a solution comprised largely of metal alkoxides is synthesized and deposited by spin coating; the resulting coating is heated to develop a crystalline ceramic layer. Fig. 2 describes the sol-gel processing method used for compatible introduction of the ferroelectric starting materials onto a gallium arsenide wafer.

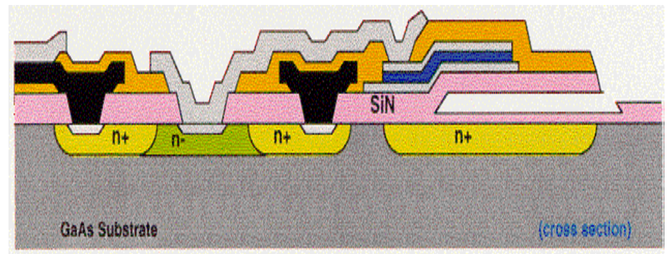

Fig. 1. Representative cross section of a GaAs-based microbeam accelerometer. The approach combines piezoelectric thin films with micromachined structures on a GaAs substrate with MESFET electronics.

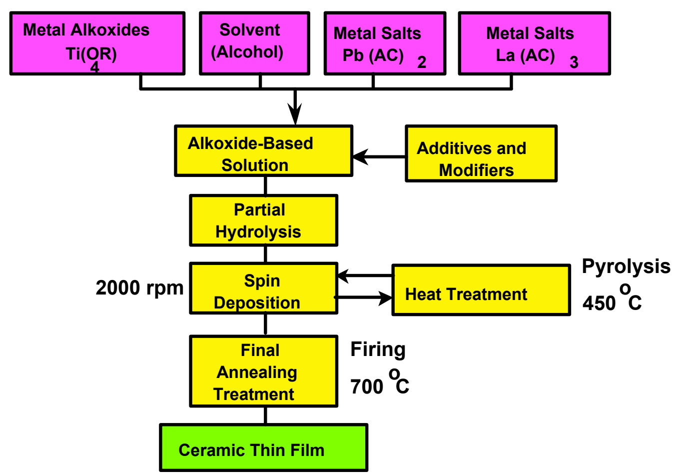

Fig. 2. Ferroelectric materials preparation method for GaAs substrates via the sol-gel route.

B. Solid-State Micromachining

Microsensors fabricated are based on both solid-state micromachining techniques and GaAs integrated circuit technology. Both hybrid and integrated microsensors are fabricated. Fig. 3 shows the fabrication method used to realize GaAs-based microaccelerometers. The major steps include a) Initial encapsulation of the GaAs wafer using PECVD SiN needed to prevent atomic out diffusion during high-temperature processing, b) Deposition and patterning of the sacrificial amorphous-silicon layer, c) Deposition and patterning of the SiN cantilever structural membrane, d) Deposition and patterning of the PZT

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capacitor stack (electrodes and piezoelectric thin film), e) Protective encapsulation of the structure using PECVD SiN, f) Selective removal of protective encapsulation layer needed to gain access to sacrificial layer, g) Solid-state micromachining of the sacrificial layer, and h) Removal of protective encapsulation layer. A finished piezoelectric microcantilever is shown in Fig. 3.

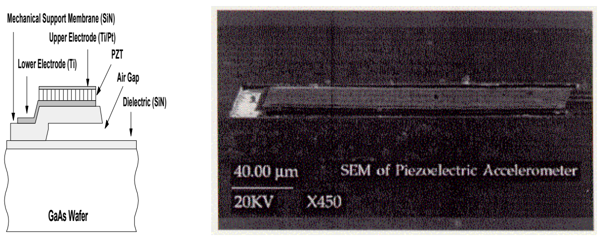

Fig. 3. Fabrication method and microphotograph of GaAs-based piezoelectric microaccelerometer.

A process design for the lead titanate pyroelectric detector was developed as shown in Fig. 4 [5-6]. Fig. 4 also shows a photo of the fabricated infrared detector. Measured data and detailed description of these microsensors and others can be found in [1-9].

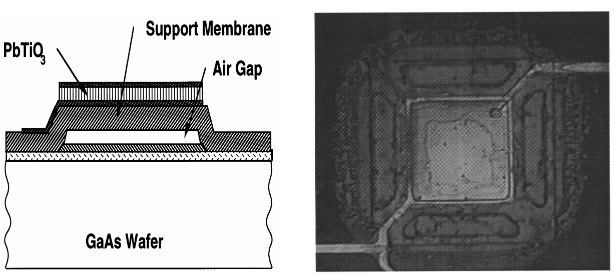

Fig. 4. Process design and microphotograph of GaAs-based uncooled infrared detector.

C. GaAs Test Chips

GaAs test chips were developed to extract process information for GaAs chip design. The test chips include a) Process diagnostic structures, b) Transistor and device diagnostic and model development structures, c) Analog functional circuit blocks, d) Digital functional circuit blocks, and e) Integrated sensor structures (Fig. 5).

D. GaAs Integrated Microsensor Processing

A GaAs n-channel metal semiconductor field effect transistor (MESFET) process was designed and successfully fabricated to realize the structures described above. The major steps of MESFET (Fig. 6) include: 1) Material initiation, 2) N+ source/drain formation, 3) N- channel formation, 4) Implant activation, 5) Ohmic contact definition, 6) First metal formation, 7) Gate/via definition, 8) Second metal/gate formation, and 9) Final sinter. The GaAs n-channel MESFET process developed was merged with the microsensor process to form the integrated microsensors. The major steps of the integrated process (microsensors plus circuits, Fig. 6) include: 1) Process MESFET through implant activation, 2) Sacrificial layer formation, 3) Sensor formation, 4) Lower electrode definition, 5) Ohmic contact and 1st metal definition, 6) Gate/via and 2nd metal definition, and 7) Sensor release. Complementary heterostructure FET integrated circuits are being developed for GaAs based microsensors [7].

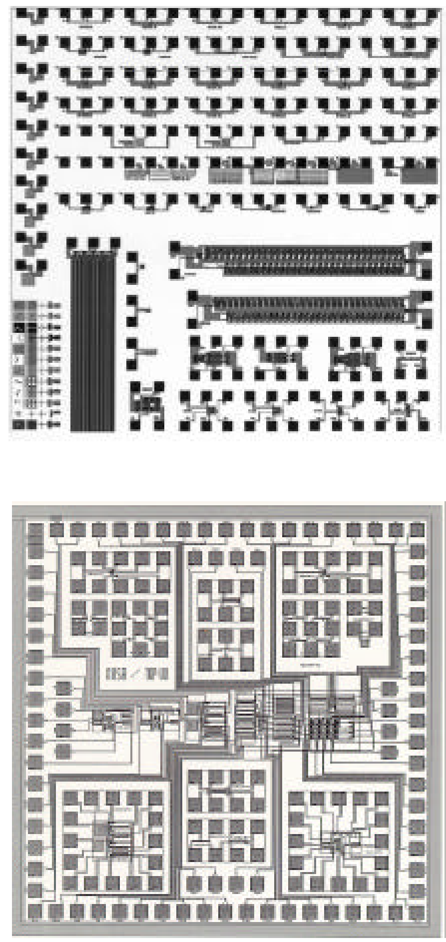

Fig. 5. Layouts of GaAs test chips.

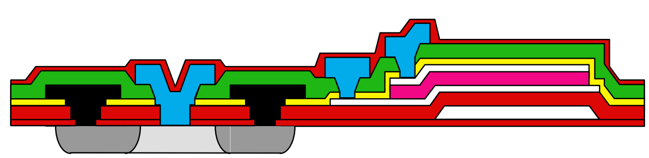

Fig. 6. GaAs MESFET integrated microsensor (sensor + circuit) process.

III. READOUT ELECTRONICS AND ANALOG TO DIGITAL CONVERTERS

Readout electronics for GaAs based accelerometers is shown in Fig. 7 [8]. The electronics include a readout circuit and an analog to digital converter. Fig. 8 shows a chip layout that was implemented in Vitesse MESFET HGaAs3 process. The chip size is 5.8 mm by 7.7 mm. The power dissipation in the digital circuits (85.7 mW) dominates the power dissipated in the analog circuits (1.6 mW). Several different types of GaAs analog to digital converters were studied and implemented [1-9].

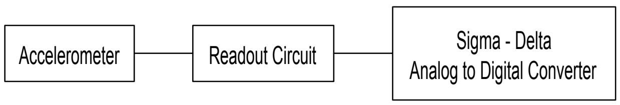

Fig. 7. Readout electronics for GaAs based accelerometers.

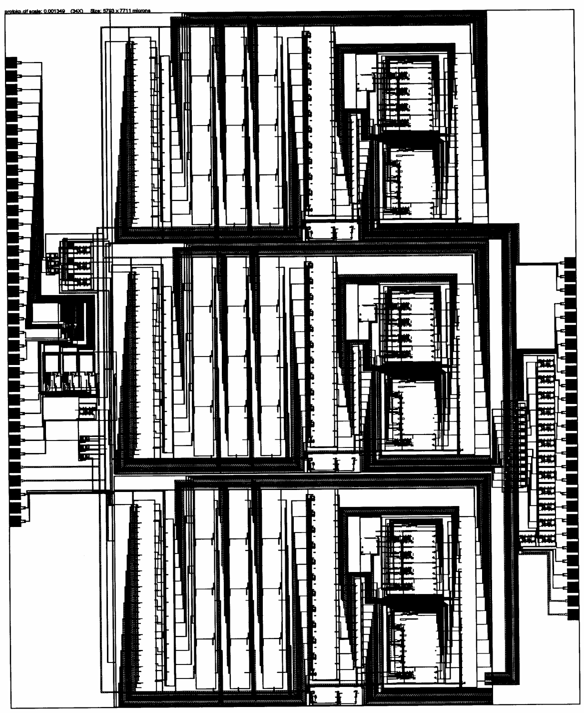

Fig. 8. Chip layout of readout electronics for GaAs based accelerometers, implemented in Vitesse MESFET HGaAs3 process (5.8 mm x 7.7 mm, 87 mW).

GaAs readout electronics for an infrared sensor is shown in Fig. 9 [3]. The electronics include transimpedance amplifiers, multiplexer, automatic gain control amplifier, correlated double sampler, and an analog to digital converter. Fig. 10 shows the chip layout of a 256x256 array readout and preprocessing electronics that was implemented in Triquint GaAs MESFET QED/A process. The chip size is 9 mm x 10.5 mm and dissipates about 12 mW.

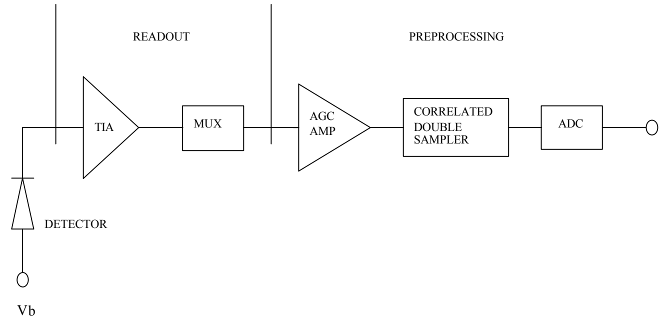

Fig. 9. GaAs readout electronics for an infrared sensor.

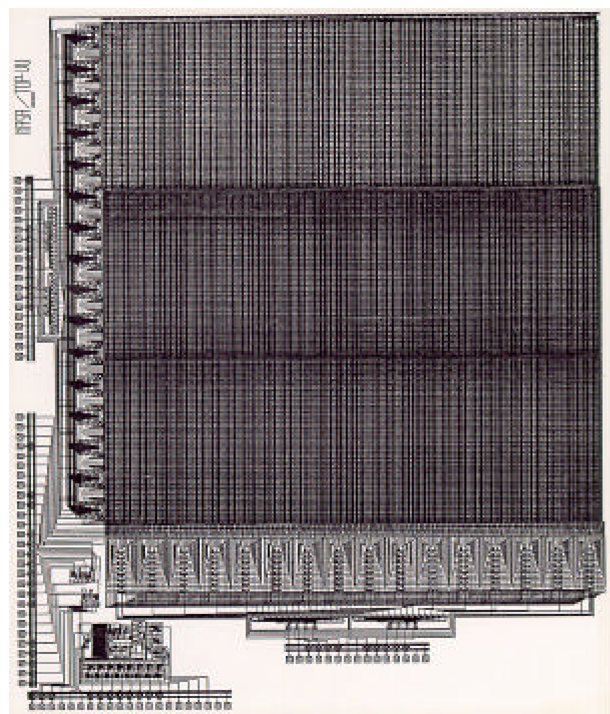

Fig. 10. Chip layout of a 256x256 infrared sensor readout and preprocessing electronics, implemented in Triquint GaAs MESFET QED/A process (9 mm x 10.5 mm, 12 mW).

VI. DIGITAL SIGNAL PROCESSORS

A GaAs digital decimation filter was implemented for a sigma-delta analog to digital converter [8]. The functions of the digital filter are to a) remove high frequency noise (filtering) and b) reduce sampling rate (decimation). Fig. 11 is a block diagram of the digital filter which includes a finite impulse response (FIR) and a decimator. The architecture includes three convolution blocks and combinatorial logics. Each convolution block has the following digital cells: adder, registers, multiplexer, demultiplexer, selector, exclusive-or gates, AND gates, OR gates, counter, and binary up/down counter. Fig. 8 shows the chip layout of a digital decimation filter.

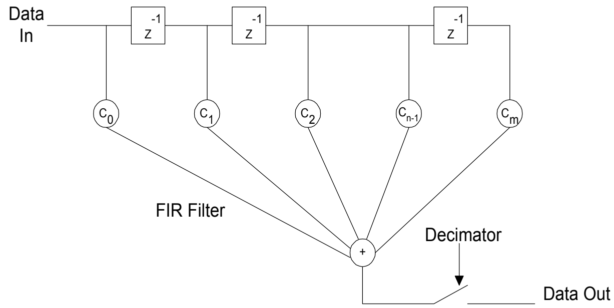

Fig. 11. Digital decimation filter.

GaAs digital signal processors (DSP's) were recommended for the infrared sensor in guidance and navigation systems [4]. Signal processing of the sensor data is performed to detect objects. The functional elements of the DSP's are shown in Fig. 12. The DSP's perform various filtering functions before segmenting them into objects for later target processing (i.e. target recognition and tracking). Dedicated processors were used for all computation intensive operations such as background subtraction, non-uniformity compensation, spatial and temporal filters, and correlation. The control dominated tasks such as thresholding, clustering and feature extraction will be implemented using a programmable processor. Transformation techniques such as pipelining, parallel processing, retiming, unfolding, folding and associativity were applied. Use of these transformations for design of high-speed or low-area and low-power DSP's were demonstrated. Trade-off of fault tolerance for different processing architectures was studied. The dedicated and programmable processors can use static, dynamic or hybrid redundancy depending on mission time systems. System characteristics of the mission and sensor were estimated for processing performance using 2 GHz clock rate.

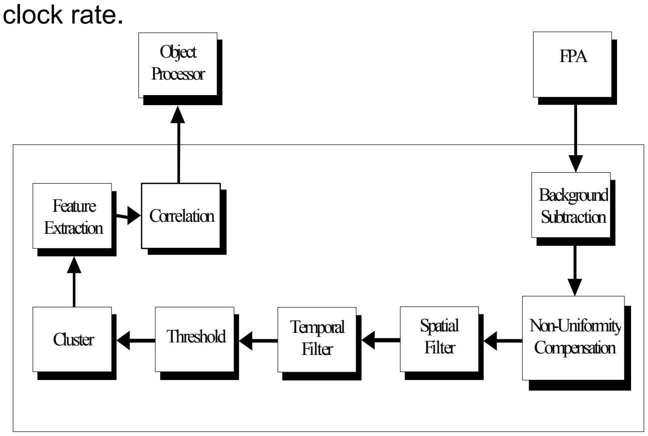

Fig. 12. Functional elements for infrared sensor digital signal processors.

V. Conclusions

Microfabrication processes for GaAs based microsensors have been in development to allow for the on-chip fabrication of GaAs integrated circuits. We have been developing GaAs readout electronics, analog to digital converters and digital signal processors for GaAs based microsensors.

Acknowledgments

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References

[1] Tho Truong Vu (Instructor), "System Insertion of GaAs Technology," IEEE 6 Hours Video Tape and Book, Short Course at International Symposium on Circuits and Systems, New Orleans LA, May 1990.

[2] T.T. Vu and J.N. Vu, "GaAs Analog Integrated Circuits and Their Potential System Insertions," Proceedings of International Symposium on Circuits and Systems, pp. 3061-4, May 1990.

[3] T. Vu, P. Nguyen, L. Vu, C. Nguyen, J. Vu, P. Wu, R. Schaumann, C. Ye, Y. Lin, R. Kotamarti, and D. Polla, "GaAs Readout and Preprocessing Electronics for Astronomy Spaceborne Infrared Focal Plane Arrays," Government Microcircuit Applications Conference Digest, pp. 195-8, November 1992.

[4] Top-Vu Technology, Inc., "Guidance and Navigation GaAs Signal Processors," U. S. Department of Defense Contract F04704-94-C-0015, Final Report, March 1994.

[5] D. Polla, P. Baude, L. Pham, Q. Mei, J. Choi, L. Francis, and T. Vu, "Micromachines Infrared Detectors Based on Pyroelectric Thin Films," Invited, SPIE Proceedings Volume 2552, pp. 602-611, 1995.

[6] Top-Vu Technology, Inc., "GaAs Based Infrared Microsensors," U. S. Department of Defense Contract DASG60-95-C-0064, Final Report, January 1996.

[7] T.T. Vu, P.C. Nguyen, L.T. Vu, C.H. Nguyen, M.D. Bui, A.C. Nguyen and J.N.C. Vu, "Complementary Heterostructure FET Technology," Invited, VTIC-97, Technologies 2000, 17-18 July 1997, San Jose CA.

[8] T.T. Vu, P.C. Nguyen, L.T. Vu, C.H. Nguyen, J.N.C. Vu, D.L. Polla, P.J. Schiller, S. Stevanovich, H.Y. Li, Y.Q. Yang, and R. Harjani, "Gallium Arsenide Based Micro-Accelerometers," Invited, 40th Midwest Symposium on Circuits and Systems, 3-6 August 1997, Sacramento California.

[9] T.T. Vu, P.C. Nguyen, L.T. Vu, C.H. Nguyen, M.D. Bui, A.C. Nguyen, J.N.C. Vu, R. Harjani, L.L. Kinney, K.K. Parhi, D.L. Polla, R. Schaumann, P.J. Schiller, and M.S. Shur, "Microsensors Fabricated In Gallium Arsenide," Technology 2007, 22-24 September 1997, Boston Massachusetts.