Chapter 6: Conclusions

Micromachined wavelength selective microbolometers operating at room temperature have been fabricated including a conventional microbolometer, resonant dielectric cavity enhanced microbolometer, and resonant air cavity enhanced microbolometer. Using surface and bulk micromachining techniques, significant improvement in thermal performance was achieved by removing the substrate from the bolometer, supporting it with long and narrow suspension legs to increase the thermal impedance. Fabry-Perot based constructive interference was produced by a mirror placed a quarter wavelength of the incoming infrared signal behind the impedance matched bolometer layer. This enhances the absorption of the microbolometer with wavelength dependency. All three fabrications processes produce a self-aligned structure for electrical isolation, which eliminates the process of further patterning the bolometer layer. The thickness of the membrane supporting the bolometer layer, which determines the resonance, should be chosen to insure that the structure of the microbolometer is mechanically stable and IC fabrication compatible. These limitations should be considered in the design of the microbolometer.

The wavelength dependency of the microbolomter was achieved by modulating the amount of power absorbed by the bolometer layer, resulting in a device with wavelength dependent response characteristics. To calculate the absorbed power coupling efficiency, a transmission line equivalent circuit model associated with the physical structure was developed. The coupling efficiency of microbolometers was modeled as a function of sheet resistance of the bolometer, thickness of the dielectric, relative dielectric constant, and incoming wavelength. Critical to achieving a high degree of wavelength selectivity in a multi-spectral microbolometer is the ability to control the thickness and quality of each multi layer stacks. If the gap between bolometer layer and mirror layer is filled with an air cavity, the first resonance is generated at a wavelength of 4 times the actual thickness of the air gap. For materials that have a large dielectric constant such as silicon nitride and silicon oxide, the effective air thickness of dielectric films is larger than the actual thickness of the dielectric films.

For characterizing the microbolometer, several measurements were performed. The TCR of chromium as bolometer layer was 0.0005 1/K, and the thermal impedance of the resonant dielectric cavity enhanced microbolometer was measured to be on the order of 10^4 K/W operating at room temperature and ambient pressure; under vacuum this would be expected to increase by tow orders of magnitude. The experimental results indicate that the measured thermal impedance was strongly affected by thermal loss to air.

The most reliable and clearest method of verification of the power-coupling model is measuring the infrared response for many narrow band incoming infrared signals. By measuring narrow band response, the entire spectral response could be reconstructed. Due to limited availability, however, a limited number of wavelengths were used to verify the model. For monochromatic HeNe laser at 1.15 and 3.39 um, the results are within the 20% between measured and response data. For broadband infrared illumination with peak wavelength of 2.75, 3.25, 4, and 4.5 μm, the optical response follows the trend, but unambiguous verification of the model is not possible due to the broad bandwidth of the illumination. It gives the ambiguity due to lack of information on wavelengths. 1/f noise is dominant for this device. The NEP was calculated to be 5 x 10^{-8} W/(Hz)$^{-1/2}$ at the modulation frequency of 1500 Hz.

One of future developments would be optimizing response of microbolometer sensors via interference effects through improving better bolometer material, configuring the leg width and length ratio, and operating device under vacuum. To enhance the wavelength selectivity for the application, four-color array may be a possible method of resolving the multi-wavelength ambiguities. The combination of efficient signal processing algorithm and scanning the response using turntable microbolometer is useful approach for resolving multi-wavelength ambiguities

Bibliography

Chapter 1

[1] Ronald G. Driggers, Paul Cox and T. Edwards, *Introduction to Infrared and Electro-Optical Systems*, Artech House, Inc., 1999.

Chapter 2

[1] Ronald G.Driggers, Paul Cox, and Timothy Edwards, *Introduction to Infrared and Electro-Optical Systems*, Artech House, Boston, 1999.

[2] Frank R. Arams, *Infrared to Millimeter Wavelength Detectors*, Artech House, 1973.

[3] J. Lewis, *Far Infrared and Sub-Millimeter Microbolometer Detectors*, PhD. Dissertation, The University of Texas at Austin, 1994.

[4] R.A Wood, "High Performance Infrared Thermal Imaging with Monolithic Silicon Focal Planes Operating at Room Temperature," *IEDM*, pp.175 – 177, 1993.

[5] P. Eriksson, J. Andersson, and G. Stemme, "Thermal Characterization of Surface Micromachnined Silicon Nitride Membranes for Thermal Infrared Detectors," *Journal of Micromechanical Systems*, Vol. 6, No.1, March 1997.

[6] C.Kittel, *Introduction to Solid State Physics, 6th edition*, New York: Willey, 1986.

[7] Y.S. Touloukian and C.Y. Ho, “Thermophysical Properties of Matter,” vol.1-3, *IFI/Plenum*, New York, 1970.

[8] V.M. Abrosimov, B.N. Ergorov, and M.A. Krykin, “Size effect of Kinetic Coefficients in Poly Crystalline Bismuth Films,” *Sov. Phys. JETP*, 37, pp.113-116, 1997.

[9] A. Jahanzeb and et al., “ A Semiconductor YBaCuO Microbolometer for Room Temperature IR imaging,” *IEEE TRACTION ON ELECTRON DEVICE*, vol.44, No.10, Oct. 1997.

[10] Sara J. Eames, Seung-Jin Yoo, John C.Warner, Dean P, Neikirk, and John T. McDevitt, "Lithographically patterned Superconductor Bolometer Detectors for Visible and Near Infrared Radiation incorporating Wavelength Selective Light Absorbing Elements", *SPIE 44th annual meeting: SPIE* Vol.3790, Denver, Colorado, July 23, 1999

[11] Peterson, K.E., “Silicon as a Mechanical Material,” *Proc. IEEE*, vol. 70, pp.420-457, May 1982.

[12] S.M. Sze, *VLSI Technology*, 2nd edition, McGraw-Hill, Inc, 1996.

[13] D. M. Tanner, “Reliability of Surface Micromachined MicroElectro Mechanical Actuators,” *Proceedings of the 22nd International Conference on Microelectronics*, Nis, Yugoslavia, pp. 97-104, 2000.

[14] L. Ristic, *Sensor Technology and Devices, Norwood,* MA: Artech House Inc., 1994.

[15] Seung-Jin Yoo, *Modeling and Fabrication of Micromachined Inductors*, MS thesis, 1997.

[16] S. Savoy, J. J. Lavigne, S.-J. Yoo, and et al. "Solution-based analysis of multiple analytes by a sensor array: toward the development of an electronic tongue," *SPIE Conference on Chemical Microsensors and Applications*, SPIE Vol. 3539, Boston, MA, Nov. 4, 1998.

Chapter 3

[1] Frank R. Arams, *Infrared to Millimeter Wavelength Detectors*, Artech House, 1973.

[2] Dieter Schroder, R. Thomas, and J. Swartz, " Free Carrier Absorption in Silicon," *IEEE Transaction on Electron Devices*, Vol. ED-25, no.2, Feb., 1978.

[3] David M. Pozar, *Microwave Engineering*, 2nd edition, John Wiley & Sons, Inc., 1998.

[4] E.D. Palik, *Handbook of Optical Constants of Solids*, Orlando, FL: Academic Press, 1985.

[5] M. Mehregany, R. Howe, and S. Senturia, “Novel Structure for the in-situ Measurement of Mechanical Properties of Thin Films”, *J. Appl. Phys.*, vol. 62, pp. 3579, 1987.

[6] M. G. Allen, M. Mehregany, R. Howe, and S. Senturia, “ Microfabricated Structures for the in situ Measurement of Residual Stress, Young’s Modulus, and Ultimate Strain of Thin Films”, *Appl. Phys. Lett.*, vol. 51, pp.241-243, 1987

[7] A. G. van Nie, “A Method for the Determination of the Stress in, and Young’s Modulus of Silicon Nitride Passivation Layers,” Solid State Technology, pp.81-84, Jan., 1980.

[8] Jaeheon Han, "Fabry-Perot Pressure and Chemical Sensors by Silicon Micromachining Techniques," Ph.D. dissertation, The University of Texas at Austin, Aug. 1996.

[9] G. R.Fowles, *Introduction of modern optics*, 2nd edition, Mineola, N.Y.: Dover Publication, 1989.

[10] A.K. Kulkarni, and L.C. Chang, “Electrical and structural characteristics of chromium thin films deposited on glass and alumina substrate,” *Thin Solid Film*, no.301, pp. 17-21, 1997.

[11] A.K. Butilenko, A.Ya. Vovk, and H.r. Khan, “Structural and electrical properties of cathodic sputtered thin chromium film,” *Surface and Coating Technology*, pp.197-199, 1998.

[12] Discussion with Dr. Neikirk

Chapter 4

[1] W. Radford, D. Murphy, M. Ray, S. Propst, A. Kennedy, J. Kojiro, J. Woolaway, and K. Soch, “320 x 240 silicon microbolometer uncooled IRFPAs with on-chip offset correction,” *SPIE* vol.2746, pp.82-92, 1996.

[2] S. M. Wentworth and D. P. Neikirk, "Composite Microbolometers with Tellurium Detector Elements," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-40, pp. 196-201, 1992.

[3] A.K. Kulkarni, and L.C. Chang, “Electrical and structural characteristics of chromium thin films deposited on glass and alumina substrate,” *Thin Solid Film*, no.301, pp. 17-21, 1997.

[4] A.K. Butilenko, A.Ya. Vovk, and H.r. Khan, “Structural and electrical properties of cathodic sputtered thin chromium film,” *Surface and Coating Technology,* pp.197-199, 1998.

[5] R.A Wood, “High Performance Infrared Thermal Imaging with Monolithic Silicon Focal Planes Operating at Room Temperature,” *IEDM*, pp.175 – 177, 1993.

[6] P. Eriksson, J. Andersson, and G. Stemme, “Thermal Characterization of Surface Micromachnined Silicon Nitride Membranes for Thermal Infrared

Detectors,“ *Journal of Micromechanical Systems*, vol. 6, no.1, March 1997.

[7] B.E. Cole, R.E, Higashi, and R.A. Wood, “Monolithic two-dimensional arrays of micromachined microstructures for infrared applications,” Proceedings of the *IEEE Piscataway,* Vol. 86, No.8, August 1998.

[8] Anisotropic Crystalline Etching Simulation (ACES), The University of Iiinois at Urbana-Champaign.

[9] S.M. Sze, *VLSI Technology,* 2nd edition, McGraw-Hill, Inc, 1996.

[10] G. Stoney, “The Tension of Metallic Films Deposited by Electrolysis,” *Proc. Roy. Soc.*, vol. A82, pp.172, 1909.

[11] A. Sinha, H. Levinstein, and T. Smith, “Thermal Stresses and Cracking Resistance of Dielectric Films on Si Substrate,” J. Appl. Phys., vol. 49, no.4, pp. 2423-2426, 1978.

12] Jaeheon Han, "Fabry-Perot Pressure and Chemical Sensors by Silicon Micromachining Techniques," Ph.D. dissertation, The University of Texas at Austin, Aug. 1996.

[13] O. Tabata, K. Kawahata, S. Sugiyama, and I. Igarashi, “Mechanical Property Measurement of Thin Films using Load Deflection of Composite Rectangular Membrane,” *Sensor and Actuators A*, vol.20, pp.135-141, 1989.

[14] D. M. Tanner, Reliability of Surface Micromachined MicroElectro Mechanical Actuators, Proceedings of the 22nd International Conference on Microelectronics, Nis, Yugoslavia, pp. 97-104, 2000.

[15] R. Maboudian and R.T. Howe, “Stiction reduction processes for surface micromachnines,” *Tribology Letters*, no.3, pp.215-221, 1997.

[16] D.C. Senft and M.T. Dugger, “Friction and wear in surface micromachined tribological test devices,” Proceedings SPIE Symposium on Micromachining and Microfabrication, Vol. 3324, Austin, pp.31-38, 1997.

Chapter 5

[1] A.K. Kulkarni, and L.C. Chang, “Electrical and structural characteristics of chromium thin films deposited on glass and alumina substrate,” *Thin Solid Film*, no.301, pp. 17-21, 1997.

[2] A.K. Butilenko, A.Ya. Vovk, and H.r. Khan, “Structural and electrical properties of cathodic sputtered thin chromium film,” *Surface and Coating Technology*, pp.197-199, 1998. [2] Frank R. Arams, *Infrared to Millimeter Wavelength Detectors*, Artech House, 1973.

[3] P. Eriksson, J. Andersson, and G. Stemme, “Thermal Characterization of Surface Micromachnined Silicon Nitride Membranes for Thermal Infrared Detectors,“ *Journal of Micromechanical Systems*, Vol. 6, No.1, March 1997.

[4] Abthony E. Siegman, Sasnett, and T.F. Johnston, Jr., “ Choice of Clip Levels for Beam Width Measurements Using Knife-Edge Techniques,” IEEE Journal of Quantum Electronics, vol. 27, no.1, April, 1991.

[5] Daniel Xavier Hammer, "Infrared Detection in MELANOPHIL ACUMINATA”, Ph.D. dissertation, The University of Texas at Austin, Dec. 2000.

Vita

Seung-Jin Yoo was born in Seoul, Korea, on July 6, 1969, the son of Tae-Rho Yoo and Kyu-Ja Han. In February 1995, he received the degree of Bachelor of Engineering in Electronics Engineering from Korea University, Seoul, Korea. In August 1995, he entered the Graduate School at the University of Texas at Austin. He has been studying on MEMS under supervision of Dr. Dean P. Neikirk since July 1996. In August 1997, He received the degree of Master of Science in Electrical and Computer Engineering from the University of Texas at Austin.

Mr. Yoo was married to Hee-sun Han on December 18, 1995 and has a daughter, Jin-hee Yoo between her.

Permanent address: 701 Hilldesheim Dokok-dong Kangnam-gu, Seoul, Korea

This dissertation was typed by the author.