Silicon Carbide Micro/Nano-Systems for Extreme Environment

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Abstract:
A number of industries such as automotive, health and energy require micro-sensors and actuators that can survive harsh environments, such as high temperatures, pressures and relative humidity. However, the materials properties of silicon impose limitations on its use in harsh environment and demanding applications. Silicon carbide (SiC) is an alternative semiconducting material that enables such applications because of its wider bandgap and higher melting/sublimation temperature, elastic modulus, fracture toughness, hardness, chemical inertness, and thermal conductivity.

This presentation will discuss recent advances in SiC-based microelectromechanical systems (MEMS) for harsh environment sensors. It will cover single-precursor chemical vapor deposition to obtain doped polycrystalline 3C-SiC (polySiC) thin films, selective reactive ion etching of SiC to pattern the deposited films, surface micromachining technology to fabricate a variety of MEMS devices, and metal-polySiC contact properties.

Introduction:
Owing to its high melting point, chemical inertness, hardness, wear resistance, and fracture toughness, polycrystalline 3C-SiC (poly-SiC) is gaining significant attention as a material of choice for micro- and nanoelectro-mechanical systems (M/NEMS) designed to operate in harsh environments [1,2]. In order for poly-SiC M/NEMS to be commercially manufactured, large-scale methods for the deposition of thin films with desirable mechanical and electrical (including metal-contact) properties as well as methods for patterning the poly-SiC layers once they are deposited must be developed and characterized.

Results and Discussions:
We have demonstrated the growth of poly-SiC thin film utilizing single precursor low-pressure chemical vapor deposition (LPCVD) at relatively low temperatures (800 °C). The precursors include 1,3-disilabutane (DSB, $CH_3SiH_2CH_2SiH_3$) and methylsilane, with the addition of dichlorosilane to tailor the mechanical properties, in particular, residual stress and strain gradient [3-5]. In-situ n-doping is demonstrated with ammonia is as the dopant gas, with resistivity values in 10mΩ.cm range obtained. These processes are then scaled up to 100 and 150 mm diameter wafers with high uniformity.

One of the challenges in fabricating SiC devices is the selective etching of SiC films or bulk materials. We have reported a highly selective reactive ion etching process for 3C-SiC films using HBr-based chemistry in a commercial transformer coupled plasma (TCP) etcher [6]. SiO_2, and Si_3N_4 are employed as etch masks. Etch rates for SiC, SiO_2, and Si_3N_4 are measured as functions of chamber pressure and TCP source power. Etch rate ratios of 20:1 for SiC/SiO_2 and 22:1 for SiC/Si_3N_4 are achieved.

For MEMS applications, the quality of metal contact to poly-SiC film is as important as the electrical and mechanical properties. An ohmic contact of low resistivity with long-term stability in harsh environments is necessary for many practical application of SiC MEMS technology. We have investigated nickel and platinum contact properties to n-type doped poly-SiC by the circular transmission line method (CTLM) at room temperature and up to 300 °C [7]. The as-deposited metal contacts (Ni and Pt) to 3% nitrogen doped polycrystalline SiC films showed ohmic characteristics. The Ni contacts to poly-SiC have the lowest contact resistivity of 1.6 $\times 10^{-6}$ Ω cm^2, The contact resistivity measurements were repeated at room temperature after 30 min annealing at 300 °C. The Ni/poly-SiC contact resistivity increases dramatically to about 1.3 x 10^{-5} Ω cm^2. The Pt/poly-SiC contact resistivity is also found to increase, but only by a factor of 2, to about 2.4 $\times 10^{-5}$ Ω cm^2. To combine low contact resistivity of Ni/SiC and the thermal stability of Pt, a Pt overlayer is applied on the top of Ni/poly-SiC. This contact resistivity, measured at 300 °C in air, only shows an initial increase and eventually stabilizes around 1.2 x 10^{-5} Ω cm^2.

Concluding Remarks:
We have successfully combined the aforementioned deposition and etching schemes to create a family of SiC-base surface micromachining processes [2] for realizing a variety of SiC-based sensors. Their

performance is evaluated in a variety of ambient, exhibiting superior behavior to their Si-based counterparts [8]. The current effort is focused on system integration, in particular of micromechanical sensors and electronics.

References:

1. C.A. Zorman, S. Roy, C.H.Wu, A.J. Fleischman, M. Mehregany, J. Mater. Res. 13 (1998) 406.
2. D. Gao, M. B. J. Wijesundara, C. Carraro, R. T. Howe, R. Maboudian, "Recent Progress toward a Manufacturable Polycrystalline SiC Surface Micromachining Technology", (invited) *IEEE Sensors* **4**, 441-448 (2004).
3. C. R. Stoldt, C. Carraro, W. R. Ashurst, D. Gao, R. T. Howe, R. Maboudian, "A Low Temperature CVD Process for Silicon Carbide MEMS", *Sensors and Actuators A-Physical* **97-8**, 410-415 (2002).
4. C. S. Roper, V. Radmilovic, R. T. Howe, R. Maboudian, "Single-source Chemical Vapor Deposition of SiC Films in a Large-scale Low-pressure CVD Reactor: Growth, Chemical, and Mechanical Characterization", *Journal of Electrochemical Society* **153**, C562-C566 (2006).
5. F. Liu, C. Carraro, J.R. Chu, R. Maboudian, "Residual Stress Characterization of Polycrystalline 3C-SiC Films on Si(100) Deposited from Methylsilane", *Journal of Applied Physics* **106**, 013505 (2009).
6. D. Gao, R. T. Howe, R. Maboudian, "High-selectivity Etching of Polycrystalline 3C-SiC Films using HBr-based Transformer Coupled Plasma", *Applied Physics Letters* **82**, 1742-1744 (2003).
7. J. C. Zhang, R.T. Howe, R. Maboudian, "Nickel and Platinum Ohmic contacts to Polycrystalline 3C-Silicon Carbide", *Materials Science and Engineering B-Solid State Materials for Advanced Technology* **139** 235-239 (2007).
8. R.G. Azevedo, J. Zhang, D.G. Jones, D.R. Myers, A.V. Jog, and B. Jamshidi, M.B.J. Wijesundara, R. Maboudian, A.P. Pisano, "Silicon Carbide Coated MEMS Strain Sensor for Harsh Environment Applications", *Technical Digest, Proceedings of 20th International Conference on Micro Electro Mechanical Systems,* MEMS'07, January 2007.