In-situ Doped Poly-SiGe LPCVD Process using BCl_3 for Post-CMOS Integration of MEMS Devices

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Poly-SiGe is a promising material for the modular integration of MEMS and CMOS, due to its low process thermal budget and its good electrical and mechanical properties [1]. B_2H_6 has been previously used for *in-situ* doping of poly-SiGe MEMS structural films, but has serious process problems. Recently, a high-throughput LPVCD process was developed for epitaxial SiGe growth using BCl_3 as dopant gas [2]. In this work, we investigate LPCVD process using BCl_3 as the dopant source for deposition of poly-SiGe MEMS structural films.

P-type *in-situ* doped poly-SiGe films were deposited in a LPCVD reactor, which is capable of both B_2H_6 and BCl_3 doping. Films were deposited at 400 mTorr, and in the temperature range of 400 - 450 °C. SiH_4 and GeH_4 were used as the gaseous Si and Ge precursors. 0.1% BCl_3 diluted in He was first used as the dopant gas, so that the BCl_3 partial pressure would be comparable to that in the previously reported epitaxial growth system [2]. The BCl_3 concentration was later changed to 1% to achieve the desired resistivity. All gases are introduced from the load side of the tube through a gas ring, except B_2H_6 is being introduced through an injector from the pump side. Targeting 70 % Ge content, poly-SiGe films were deposited on Si wafers coated with ~2 µm thick oxide.

Fig. 1 plots boron concentration *vs.* dopant gas partial pressure for the poly-SiGe depositions. As a comparison, data for epi-SiGe deposition [2, 3] is also shown. The two order of magnitude difference in dopant incorporation of the two systems comes from the deposition temperature, the oxygen contamination level, the substrate surface, the germanium content, and the deposition rate. A data point from the B_2H_6 process is also shown in Fig. 1. A high B_2H_6 partial pressure is required to achieve similar doping levels in the film while other deposition conditions are identical. The high consumption of B_2H_6 is mainly due to its decomposition rather than the disassociation.

Deposition rate and resistivity of the poly-SiGe are plotted vs. wafer position in Fig. 2 to demonstrate the cross load uniformity of the BCl_3 process. Wafers at the gas inlet side have higher deposition rate and lower resistivity, which suggests a gas depletion effect. Increasing the gas flow rate along with using an injector to introduce BCl_3 could result in better cross load uniformity. A B_2H_6 deposition is also shown in Fig. 2 as a reference. Cross load variation in deposition rate and resistivity is similar to the BCl_3 process, despite the fact that B_2H_6 is introduced via a multi-pore injector.

Comparing films with similar thickness and boron doping as the only process variable, we can see that the average residual stress is more compressive as boron doping increases, as shown in Fig. 3. This possibly indicates the boron atoms are not residing in substitutional lattice sites, but interstitial lattice sites or grain boundaries. A data point from the B_2H_6 process shows that the average stress for B_2H_6 doped film is less compressive for the same level of doping. However, 0.6 µm films are too thin for most MEMS applications, and the 1.7 µm thick BCl_3 doped film with 6.0×10^{18} cm^{-3} doping yields reasonably low residual stress at -20.9 MPa.

The better uniformity and higher doping efficiency for the BCl_3 process is clearly advantageous over the B_2H_6 process for poly-SiGe films, but degradations in deposition rate and increases in residual stress are the tradeoffs. Tradeoffs between residual stress and resistivity are also involved in optimizing boron concentration for the BCl_3 doped process. Both residual stress and resistivity can be improved by increasing the film thickness. Thicker films also have advantages in strain gradient and grain crystallinity, and thicker films are desired for better electro-mechanical performance in MEMS applications.

References:

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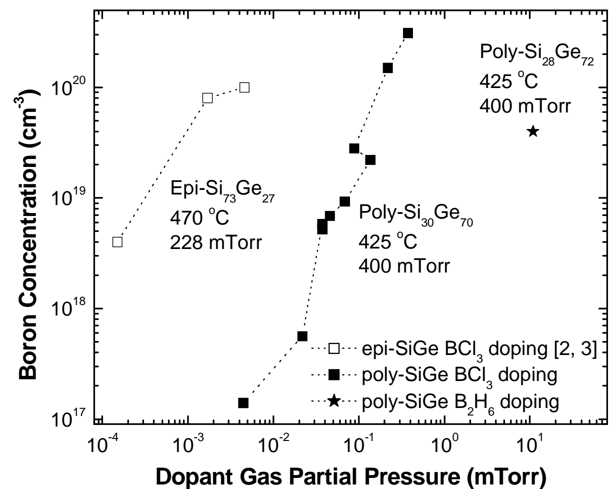

Fig. 1 Boron concentration vs. Dopant gas partial pressure

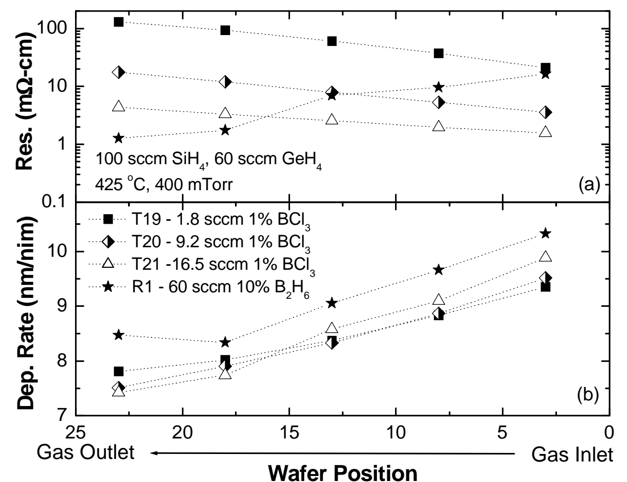

Fig. 2 Deposition rate and resistivity across load

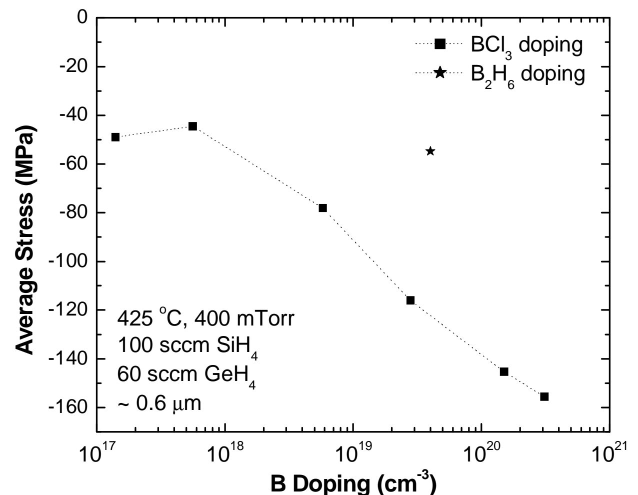

Fig. 3 Average stress vs. Boron doping