Effect of addition of elements in group IVB (C, Si, Ge, Sn) on polarity inversion of Scandium Aluminum Nitride (ScAlN) piezoelectric thin films

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The outstanding piezoelectricity of scandium aluminum nitride (ScAlN) has successfully brought improvement to the performance of radio frequency (RF) filter for wireless communication [1,2]. With the arrival of 5G communication era, the RF filter is required to work at much higher frequency and wider bandwidth to allow larger data transfer. One way to improve the performance of a RF filter is by employing multilayers of piezoelectric thin films with different polarities, for example the use of Al-polar AlN/N-polar germanium aluminum nitride (GeAlN) has enabled a solidly mounted resonator BAW (SMR-BAW) to function at much higher frequency [3]. Based on those findings, the utilization of a stack of Al-polar and N-polar ScAlN-based thin film is expected to enhance the performance of RF filter compared with that using one layer of ScAlN with single polarity. Thus, controlling the polarity of ScAlN piezoelectric thin film is paramount for the development of next generation RF filter. As a method to control the polarity, addition of element such as silicon (Si) or germanium (Ge) into AlN has been reported to successfully inverse the polarization direction of aluminum nitride (AlN) [3,4] as well as ScAlN [5,6]. Since Si and germanium (Ge) belong to the group IVB in the periodic table, we investigated the effect of addition of each element in group IVB (carbon (C), Si, Ge, tin (Sn)) on the polarity of ScAlN thin films.

All thin films were deposited on Si (100) wafer via reactive sputtering by using RF magnetron sputtering system. The concentration of each element was controlled by adjusting the power of cathodes for each corresponding target during thin film deposition. All elements in thin films were investigated by using energy dispersive spectroscopy (Horiba, Japan). The piezoelectric response (d_{33}) was examined using Piezometer (Piezotest PM300, UK). Positive d_{33} value indicates that the thin film has metal-polar while negative d_{33} value indicates that the thin film has N-polar. The positive d_{33} values exhibited by $Sc_xAl_{1-x}N$ suggest that the polarity of $Sc_xAl_{1-x}N$ thin film is Al-polar. As shown in Fig. 1, addition of C into ScAlN was found to results in thin films with positive d_{33}, which means addition of C into ScAlN is unable to inverse the polarity of ScAlN. However, addition of each of Si and Ge into ScAlN resulted in thin films with negative d_{33} values that has similar magnitude with ScAlN, suggesting addition of each of Si or Ge is not only could inverse the polarity of ScAlN but also capable of maintaining the value of d_{33}. Meanwhile addition of Sn into ScAlN resulted in thin film with N-polarity, but the value of d_{33} is slightly lower than that of ScAlN. The formation of N-polar ScAlN is controlled by both concentration of each additive element (in this case: Si, Ge, Sn) and the concentration of Sc. Effect of these elements' addition on polarity distribution, crystal structure and surface states were also investigated in this study.

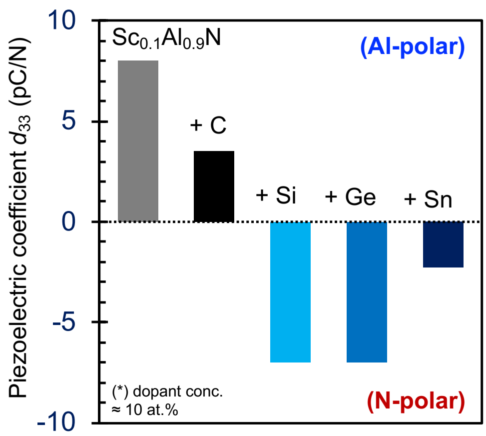

Figure 1 Effect of addition of each element in Group IVB on the polarity of ScAlN thin films

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