ALD HfO_2, Al_2O_3, and PECVD Si_3N_4 as MIM Capacitor Dielectric for GaAs HBT Technology

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The die size in semiconductor wafer manufacturing must be reduced, due to the increasing demand for capacity and increasing complexity and functionality of devices in IC designs. One of the methods to reduce the die size is to increase the capacitance density of the metal-insulator-metal (MIM) capacitor, which is a key passive component in GaAs RF designs. A higher capacitance density capacitor will allow the reduction of the capacitor area, resulting in die size reduction. This will also allow the integration of additional capacitors on to the chip, including off-chip capacitors, thereby reducing the bill-of-materials in a multi-chip module. In addition to high capacitance density, the MIM capacitor in GaAs technology typically also requires high breakdown voltage, low leakage current, and high quality factor. The most widely used MIM capacitor dielectric in GaAs technology is plasma-enhanced chemical vapor deposition (PECVD) silicon nitride (Si_3N_4). This film is known to have relatively good electrical, physical, and chemical characteristics. It is also compatible with GaAs technology, and can be deposited at temperature of $\leq$300^{o}C. However, PECVD Si_3N_4 has only a dielectric constant κ of only 6-7, resulting in capacitance density that is relatively low.

Recently, atomic layer deposition (ALD) method has been used to deposit high quality dielectric films at low temperatures. In this study, we have evaluated and characterized ALD hafnium dioxide (HfO_2) and aluminum oxide (Al_2O_3) as MIM capacitor dielectric for GaAs hetero-junction bipolar transistor (HBT) technology, and compared the results to those of PECVD Si_3N_4. All three films were 60 +/- 3 nm thick. The ALD HfO_2 was deposited at 230^{o}C using tetrakisethylmethylamino hafnium, water, and O_3, while the ALD Al_2O_3 was deposited at 300^{o}C using are trimethyl aluminum, water, and O_3. The PECVD Si_3N_4 was deposited at 300^{o}C using SiH_4, NH_3, and N_2. Fig. 1 shows the capacitance density obtained when these 3 films were used as MIM capacitor dielectric. As can be seen, the capacitance density of MIM capacitor with ALD HfO2 (2.73 fF/μm^2) and Al_2O_3 (1.55 fF/μm^2) is significantly higher than that with PECVD Si_3N_4 (0.92 fF/μm^2). Fig. 2 shows that the dielectric constant of ALD HfO_2 and Al_2O_3 is 18.7 and 10.3, respectively, as compared to that of PECVD Si_3N_4 which is 6.5. However, the breakdown field of the ALD HfO_2 (5.4 MV/cm) and Al_2O_3 (7.0 MV/cm) is lower than that of PECVD Si_3N_4 (11.6 MV/cm). Fig. 3 shows the IV characteristics of these 3 films, when the temperature was increased from 25^{o}C to 150^{o}C. The results show that as the temperature was increased, the leakage current density of all films increased. However, the PECVD Si_3N_4 leakage current density is significantly less than that of both ALD HfO_2 and Al_2O_3. Furthermore, the data also show that the breakdown voltage of ALD HfO_2 and Al_2O_3 is lower than that of PECVD Si_3N_4, and is reduced significantly more when the temperature was increased from 25^{o}C to 150^{o}C. Fig. 4 shows the quality factor of the MIM capacitor extracted from S-parameter measurement, when these three films were used as capacitor dielectric on GaAs HBT wafers. It can be observed that the quality factor of the MIM capacitor with ALD HfO_2 and Al_2O_3 is lower than that with PECVD Si_3N_4 by about 50%.

These results show that each of the three films of ALD films of HfO_2 and Al_2O_3, and PECVD Si_3N_4 have different advantages in terms of electrical characteristics. The ALD films in this study have significantly higher capacitance density than PECVD Si_3N_4. However, the PECVD Si_3N_4 has lower leakage current, higher breakdown field, and higher quality factor than the ALD films. These data show that the ALD HfO_2 and Al_2O_3 films, in addition to the PECVD Si_3N_4 film, can be used as MIM capacitor dielectric for GaAs HBT technology, and can be selected based on the GaAs HBT MIM capacitor specific electrical characteristics requirements, application, and operating conditions.

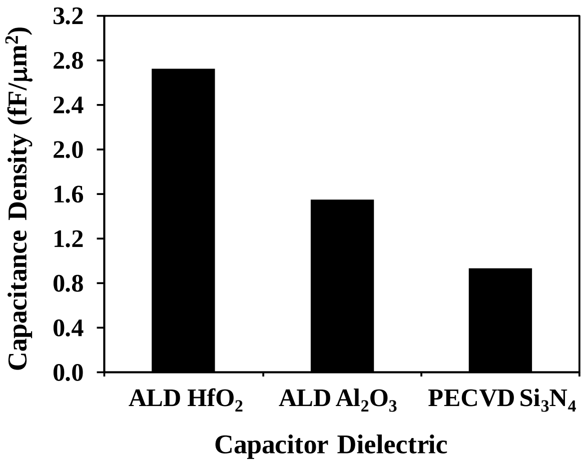

Fig 1. Capacitance density of MIM capacitor with 60+/-3 nm of ALD HfO_2, ALD Al_2O_3, and PECVD Si_3N_4 as capacitor dielectric on GaAs.

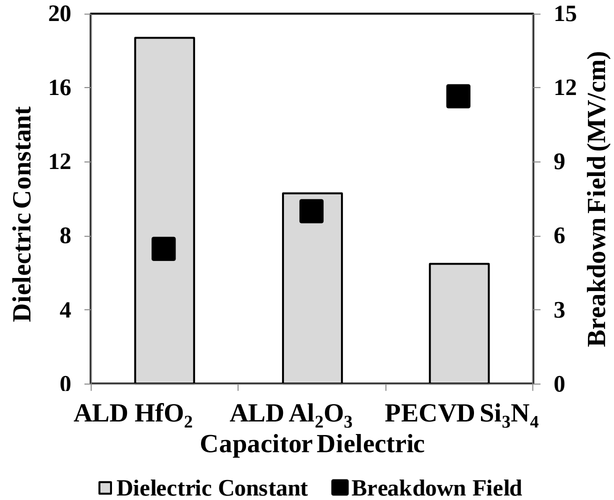

Fig 2. Dielectric constant and breakdown field of ALD HfO_2, ALD Al_2O_3, and PECVD Si_3N_4.

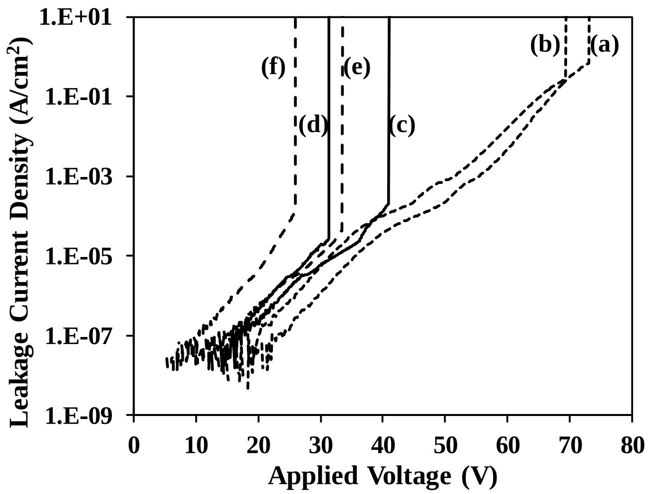

Fig 3. The I-V characteristics of GaAs MIM capacitor with capacitor dielectric 60+/-3 nm (a) PECVD Si_3N_4 at 25°C, (b) PECVD Si_3N_4 at 150°C, (c) ALD Al_2O_3 at 25°C, (d) ALD Al_2O_3 at 150°C, (e) ALD HfO_2 at 25°C, and (f) ALD HfO_2 at 150°C.

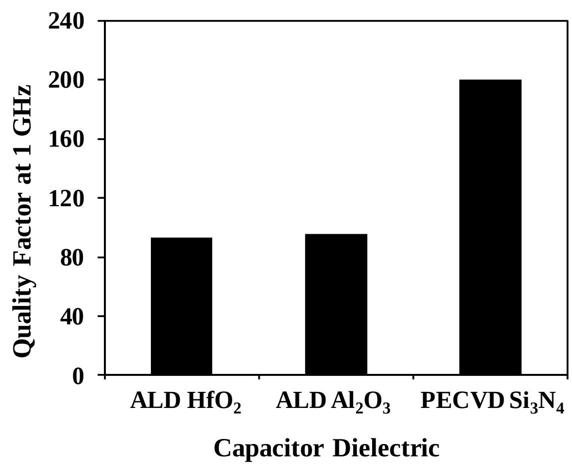

Fig 4. Quality factor of MIM capacitor with 60+/-3 nm of ALD HfO_2, ALD Al_2O_3, and PECVD Si_3N_4 as capacitor dielectric on GaAs.