Sensing properties of thin Nd$_2$O$_3$ sensing membrane for pH-ISFET

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The original SiO$_2$ material used as a pH-sensitive membrane for the ion sensitive field effect transistor (ISFET) was introduced by Bergveld [1] in 1970. This material has some issues in the ISFET sensing structure, such as the poor isolation between the devices and the chemical solutions, and the low sensitivity. A number of metal oxides including Ta$_2$O$_5$, TiO$_2$, and Al$_2$O$_3$ [2-3] have been proposed as an ion sensing membrane for pH-sensitive ISFET applications due to their high sensitivity performance. However, the poor interface often exists between the metal oxide and Si substrate [4]. Recently, thin rare-earth metal oxide (Nd$_2$O$_3$) films are currently being investigated as high-k materials to replace SiO$_2$ because they possess high dielectric constants, large band gaps, and thermodynamic stability with Si [5].

The electrolyte-insulator-semiconductor (EIS) devices with Nd$_2$O$_3$ sensing films were fabricated 4-in p-type (100) Si wafers. Thin Nd$_2$O$_3$ films were deposited on the Si substrate by reactive sputtering. Then, the sample was performed using a conventional rapid thermal annealing (RTA) system in an oxygen ambient for 30s at various temperatures. A 4000-Å-thick Al film was deposited as the backside contact of the Si wafer. The sensing membrane size was defined through photolithographic processing under a photosensitive epoxy that behaves as an antiacid polymer. EIS devices were then fabricated on the copper lines of a printed circuit board by using a silver gel to form conductive lines. A hand-made epoxy package was employed to separate the EIS structure and the copper lines.

Fig. 1 demonstrates one group of C–V curves of EIS device with a thin Nd$_2$O$_3$ film in different pH buffer solutions. The variation in a pH solution is a shift in the flatband voltage of the C–V curves. This behavior can be explained by using the site-binding model [6]. As a result of the shift, a group of C–V curves can be obtained as a function of different pH solutions. The reference voltage of Nd$_2$O$_3$ sensing membranes annealed at 700 °C as a function of pH is shown in Fig. 2. The reference voltage is obtained from the C–V curve for achieving the normalized capacitance of 0.2. The results indicate that the shift of reference voltage for EIS device with a Nd$_2$O$_3$ sensing film is 55.6 mV/pH. The hysteresis voltage of EIS device with Nd$_2$O$_3$ sensing membranes as a function of RTA temperatures during the pH loops of pH2 → pH7 → pH10 → pH12 was shown Fig. 3. From the experimental results, the hysteresis voltage of Nd$_2$O$_3$ sensing membrane annealed at 700 °C is smaller than other annealing temperatures. This is because of the smooth surface of Nd$_2$O$_3$ sensing membrane. Furthermore, the acid-side hysteresis was smaller compared to the base-side one. The size of H$^+$ ion and OH$^-$ ion are different, the diffusion speed of H$^+$ ions are faster than OH$^-$ ions. Fig. 4 shows the drift rate of EIS capacitors having Nd$_2$O$_3$ sensing membranes as a function of RTA temperatures.

The as-deposited sample has a higher drift rate, suggesting a rougher surface. EIS capacitor using a Nd$_2$O$_3$ sensing membrane after RTA at 700 °C exhibits a lower drift rate compared to other RTA temperatures. This is due to the small surface roughness of Nd$_2$O$_3$ film.

References


Fig. 1. CV curves response of Nd$_2$O$_3$ sensing films after RTA at 700 °C when inserted into solutions with pH values from 2 to 12.

Fig. 2. Reference voltage of an Nd$_2$O$_3$ gate ISFET annealed at 700 °C as a function of pH at room temperature.

Fig. 3. Hysteresis voltage as a function of RTA temperatures for Nd$_2$O$_3$ sensing membranes during the pH loops of 7 → 7 → 10 → 12 and 7 → 10 → 7 → 4 → 7.

Fig. 4. Drift rate as a function of RTA temperatures for Nd$_2$O$_3$ sensing membranes.