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A NEW APPROACH TO LOW DRIFT Ta$_2$O$_5$ pH-ISFET BY RF REACTIVE SPUTTERING AND SOL-GEL METHOD

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SUMMARY

Thin films, such as SiO$_2$, ZrO$_2$, Al$_2$O$_3$, Si$_3$N$_4$ and Ta$_2$O$_5$ were known as hydrogen ion sensing membranes for pH-ISFET[1]. Among them, Ta$_2$O$_5$ thin film was reported to have the better sensing characteristics than those of other hydrogen ion sensing membranes.

In this research, the Ta$_2$O$_5$ hydrogen ion sensing membrane were formed by RF reactive sputtering and Sol-Gel method. Ta$_2$O$_5$ pH-ISFETs by RF reactive sputtering and Sol-Gel method showed a good linearity in wide pH range (pH 2 to 12) and had high sensitivities of 58-59mV/pH and 57mV/pH, respectively. Especially, Ta$_2$O$_5$ pH-ISFET by RF reactive sputtering showed stable long-term sensitivity (57~59mV/pH) during 45 days and long-term stability during 60 days (0.05pW/day).

RF REACTIVE SPUTTERING METHOD

Table 1 is the optimum conditions for the formation of the Ta$_2$O$_5$ membrane by RF reactive sputtering. The conditions were determined from investigation on the physical properties (refractive index, etching ratio, dielectric constant and composition ratio) and electrical properties (C-V characteristics and leakage current) of the thin films.

Hydrogen ion sensing characteristics of the Ta$_2$O$_5$ pH-ISFET by RF reactive sputtering is shown in figure 1. This sensor showed a good linearity within the wide pH range (pH 2 to 12) and high sensitivity (about 59mV/pH), which was very close to the theoretical Nernst potential.

![Figure 1. Hydrogen ion sensing characteristics of Ta$_2$O$_5$ pH-ISFET by RF reactive sputtering.](image)

The long-term stabilities of the pH-ISFET measured in the pH 7 solution are shown in figure 2. The pH-ISFET annealed by conditions shown in table 1 had the best stability of about 0.05pH/day during 60 days. XRD analysis showed that the crystal...

| RF power | 50W |
| Working pressure | 50mtorr |
| Gas mixture ratio(Ar/O$_2$) | 4:1 sccm |
| Substrate temp. | 200°C |
| Annealing conditions | O$_2$, 400°C, 1hr |

Table 1. Ta$_2$O$_5$ sputtering and annealing conditions(2).
structure of the annealed Ta$_2$O$_5$ film was changed from amorphous to poly-crystalline structure in the vicinity of 500°C. As shown in figure 3, the long-term sensitivities of pH-ISFET annealed in O$_2$ ambient was maintained at about 57~59mV/pH, while that of pH-ISFET annealed in N$_2$ ambient much varied with time.

SOL-GEL METHOD

From the previous results, we can see that the Ta$_2$O$_5$ gate pH-ISFET by RF sputtering has the better sensing characteristics than the results of the reference(3), but it needs to be still improved in the long-term stability. The dominant factor of the drift will be the hydration or memory effect of the membrane(4). If the ultra-thin membrane is formed, paradoxically the hydration will be completed within a very short time, and the above-mentioned problems may be solved. In this work, we tried to form the ultra-thin Ta$_2$O$_5$ membrane by using Sol-Gel method. The solution for the fabrication of Ta$_2$O$_5$ films is prepared as

Figure 2. Long-term stabilities of the Ta$_2$O$_5$ pH-ISFET by RF reactive sputtering.

Figure 3. Long-term sensitivities of Ta$_2$O$_5$ pH-ISFET by RF reactive sputtering.
described in figure 4. The prepared solution was spin-on coated on the SiN₄ gate pH-ISFET and heat-treated at 400°C to remove the remaining organics. The membrane formed with this process had ultra-thin thickness (about 100Å), which was measured by ellipsometric method. Figure 5 is XRD patterns of Ta₂O₅ film according to heat treatment conditions. The film showed a amorphous structure with heat treatment temperature below 600°C, while poly-crystalline structure was formed by heat treatment at 800°C in the O₂ ambience. We determined heat treatment conditions to be 400°C (O₂ ambience, 1 hour) because the leakage currents began to increase in the films annealed above 400°C. Figure 6 is an AES depth profile of Ta₂O₅ thin film heat-treated at 400°C. This figure shows that oxygen, the sensing site for hydrogen ions, is more rich at the surface than in the bulk.

Hydrogen ion sensing characteristics of Ta₂O₅ pH-ISFET by Sol-Gel method are shown in figure 7. This sensor showed a good linearity in the wide pH range (pH 2 to 12) and high sensitivity (about 57mV/pH). From these results, we see that Ta₂O₅ thin film by Sol-Gel method can be applied to hydrogen ion sensing membrane.

CONCLUSION

The Ta₂O₅ pH-ISFET by RF reactive sputtering had a good linearity in the wide pH range (pH 2 to 12), high sensitivity (about 58~59mV/pH), stable long-term stability (about 0.05 pH/day), and good...
long-term sensitivity (57–59 mV/pH). These results were better than those of previously reported papers [3].

In this research, we tried to form ultra-thin Ta₂O₅ membrane for improving the drift of pH-ISFET by Sol-Gel method. By introducing Sol-Gel method, Ta₂O₅ film having about 100 Å thick was formed. This sensor showed a good linearity and high sensitivity (about 57 mV/pH) in the range of pH 2 to 12. From above result, we see that Ta₂O₅ membrane by Sol-Gel method can be used in the hydrogen ion sensing membrane.

More detailed studies are now in progress to improve the long-term stability by Sol-Gel method.

REFERENCES