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A concave-type structure of a Ru electrode capacitor fabricated by the reactive ion etching method

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Abstract

We have developed a concave-type Ru electrode capacitor to overcome the limitation of conventional stack-type capacitor in a small critical-dimension (CD) pattern. We have deposited a Ru layer on the concave-type structure made by patterning of SiO_2 and subsequently we separated the adjacent nodes by an etch-back process with hydrogen silsesquioxane (HSQ) as a protecting layer. We have summarized the issues regarding the patterning in the reactive ion etching system for fabricating the concave-type capacitor.

Keywords: Ru; Etching; Concave; Scanning electron microscopy

1. Introduction

As dimensions of devices are getting smaller and smaller, high dielectric materials, such as barium strontium titanate (BST), tantalum pentoxide (Ta_2O_5), need to be used for the fabrication of dynamic random access memory (DRAM) capacitors [1–4].

For those dielectric materials to be stabilized, the capacitor electrode should be inert and preferably not oxidized and thus Pt, Ru, and RuO_2 has been considered. Since platinum (Pt) has usually been investigated as an electrode material, the Pt etching technique has been developed [5–7]. However, several research groups have reported that obtaining sufficient etching selectivity of Pt to the mask material is very difficult [8–11].

On the other hand, ruthenium (Ru) or RuO_2 is expected to be patterned by chemical etching because the volatile etch product can be produced [12,13]. In patterning the Ru electrode, the conventional photoresist mask cannot be used because the O_2-based plasma needs to be used for Ru etching.

In order to use Ru as an electrode material in the stacked capacitor cell structure successfully, in order to pattern the bottom electrode a Ru etching technique needs to be developed. Although several researchers have reported on the successful etching of Ru electrode and show the possibility of fabricating the stack-type capacitor using the Ru electrode [14,15], obtaining the vertical Ru etching slope with a high-enough etch rate is still difficult. When the Ru has a low etch slope and thus the adjacent nodes are connected with Ru, the bottom Ru storage nodes

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cannot be separated from their adjacent storage nodes.

In order to allow for lateral shrinkage of the cell sizes while keeping the required cell capacitance, without employing the difficult Ru electrode etching, we have developed a concave-type cell structure, revealing that the above method is suitable to the storage node pattern in the CD of 0.17 μm and below. As far as we know, this is the first report on the concave-type structure of Ru electrode capacitor.

2. Experimental

The fabrication sequence of the concave-type capacitor is described in Fig. 1 and in a previous report [16]. The thin anti-reflection coating (ARC) layer (<30 nm) has been deposited on top of a SiO_2 layer prior to PR coating, to prevent unnecessary reflection during lithography. After forming a concave structure with SiO_2, the bottom electrode Ru layer is deposited and subsequently the protective hydrogen silsesquioxane (HSQ) layer is coated. In order to reduce the thickness of the HSQ layer and expose the top part of the Ru layer, HSQ etchback is performed. Ru etchback is then performed to isolate the Ru layer of each concave structure. After removing the remaining HSQ layer, BST and the top electrode Ru layer are deposited to form a capacitor.

The schematic of a reactive ion etcher (RIE) used in this work is shown in our previous work [17]. The combination of high radio frequency power (HRF), 13.56 MHz and low radio frequency power (LRF), 450 kHz, in addition to the low operating pressure (<10 mTorr) result in high-energy ion bombardment. The SiO_2 etching was performed to make a concave structure and a mixture of Ar, CF_4, and CHF_3 gas was used as an etchant. In the HSQ etchback process, the Ar, CF_4, and CHF_3 gas was used as an etchant. In the Ru etchback process, the O_2 gas and Cl_2 gas were employed as an etchant.

3. Results and discussion

We have fabricated a concave structure with SiO_2 in a pattern with a CD of 0.17 μm, using the $Ar/CF_4/CHF_3$ plasma. The SiO_2 to PR etch selectivity increases by decreasing the LRF power, by increasing the CHF_3 flow-rate, and by increasing the HRF power. We have used an etching condition with a HRF power of 700 W, a LRF power of 0 W, a CHF_3 flow-rate of 90 sccm, and a pressure of 70 mTorr, resulting in a SiO_2 to PR etch selectivity of 2.4 and obtaining a vertical profile.

After forming the concave-type structure by etching the SiO_2 layer, we deposit the Ru layer which is used as the bottom electrode of the capacitor. On top

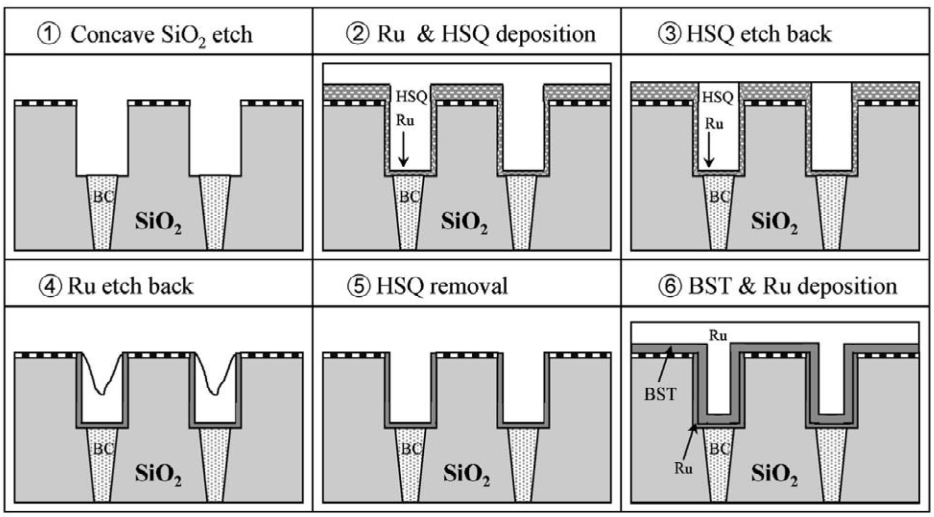

Fig. 1. The fabrication sequence of concave-type Ru/BST/Ru capacitor (‘BC’ represents the buried contact).

of it, we coat the HSQ layer to protect the underlying Ru layer. Since only the Ru layer inside the hole of the concave structure is utilized as the bottom electrode, the coated HSQ layer and subsequently the Ru layer outside the hole needs to be removed. For the HSQ etchback process, the chamber pressure is 30 mTorr and the Ar, CF_4, and CHF_3 gas flow-rates are 100, 50, and 50 sccm, respectively. The HRF (13.56 MHz) power and the LRF (450 kHz) power are set to 600 W and 100 W, respectively. The resulting HSQ etch rates in the bulk region and inside the concave hole are 827 and 1250 Å/min, respectively. Fig. 2a, b show the typical SEM images of the concave-type structure when the bottom electrode and the HSQ layers are deposited and when the HSQ etchback is performed, respectively. We reveal that the Ru layer outside the concave hole is slightly exposed after the etchback process and the Ru layer is not eroded due to the sufficiently high (~ 30 mTorr) etching pressure and resulting extremely low Ru etch rate of less than 10 Å/min. Fig. 2b reveals the generation of the HSQ spacer during the HSQ etchback process.

In order to separate the Ru layer inside each concave hole and to form a bottom electrode, we remove the Ru layer deposited outside the concave hole by the etchback process. In this step, the Ru to HSQ etch selectivity needs to be sufficiently high, otherwise the HSQ layer inside the hole will be eroded away. For the Ru etchback process, the chamber pressure is 30 mTorr and the O_2 and Cl_2 gas flow-rates are 320 and 80 sccm, respectively. The HRF (13.56 MHz) power and the LRF (450 kHz) power are set to 800 W and 100 W, respectively. In the Ru etchback process, the etch rates of HSQ and Ru are about 20 and 240 Å/min, respectively. Fig. 3 shows the profiles of the concave-type structure after the etchback of Ru bottom electrode layer.

The height of the remaining HSQ inside the concave hole should be optimized. If the height is too low, the HSQ layer protecting the bottom Ru electrode may be completely eroded during the following Ru etchback process and the bottom Ru layer could be damaged. On the other hand, if the height is too high, the sidewall of the concave hole has an excessive HSQ spacer and this spacer covers the Ru layer. Therefore, during the following Ru etchback process, the Ru layer underneath the SiO_2 spacer cannot be etched and the cusped crown-shaped Ru can be generated. Fig. 4 shows the resulting cusped crown-shaped Ru, from insufficient HSQ etchback.

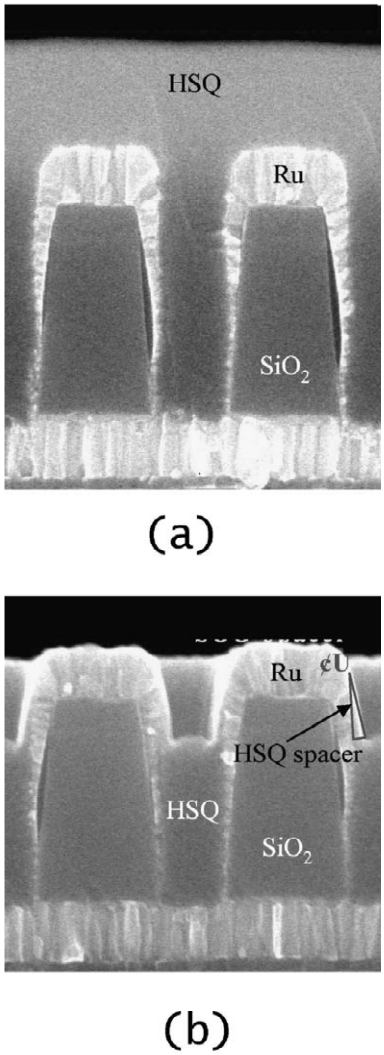

Fig. 2. SEM images of the concave-type structure (a) when the Ru bottom electrode and the HSQ layers are deposited and (b) when the HSQ etchback is performed.

Fig. 5 shows the profiles of the concave-type structure after the removal of the remaining HSQ layer using the aqueous HF solution. The HF solution has enough HSQ to SiO_2 etch selectivity. The SEM image indicates that a very small spacing can be generated between the Ru and the surrounding

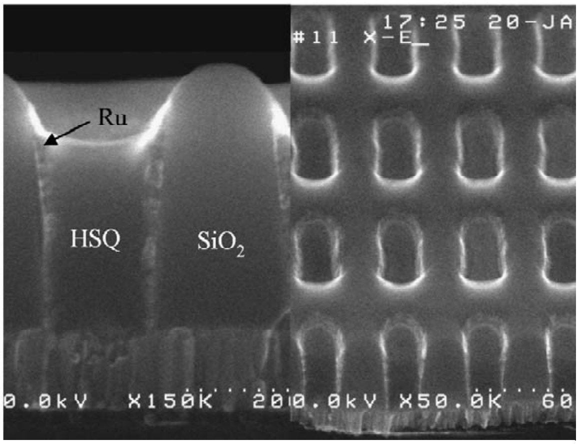

Fig. 3. SEM images of the concave-type structure after the etchback of Ru bottom electrode layer.

SiO_2 during the following HF treatment, by the penetration of HF solution. We surmise that this observation is closely related to the generation of the cusped crown-shaped Ru structure. Further study is underway to reveal the detailed mechanism.

In order to prevent the penetration of the HF solution, we have inserted the thin Ta_2O_5 layer on

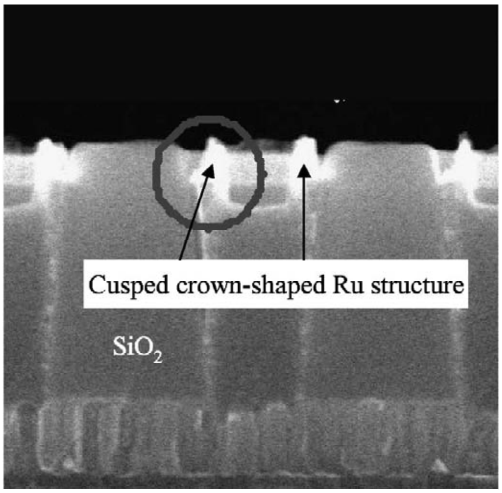

Fig. 4. SEM image of the concave-type structure after the etchback of the Ru bottom electrode layer, indicating that the cusped crown-shaped structure is generated due to insufficient removal of the HSQ layer.

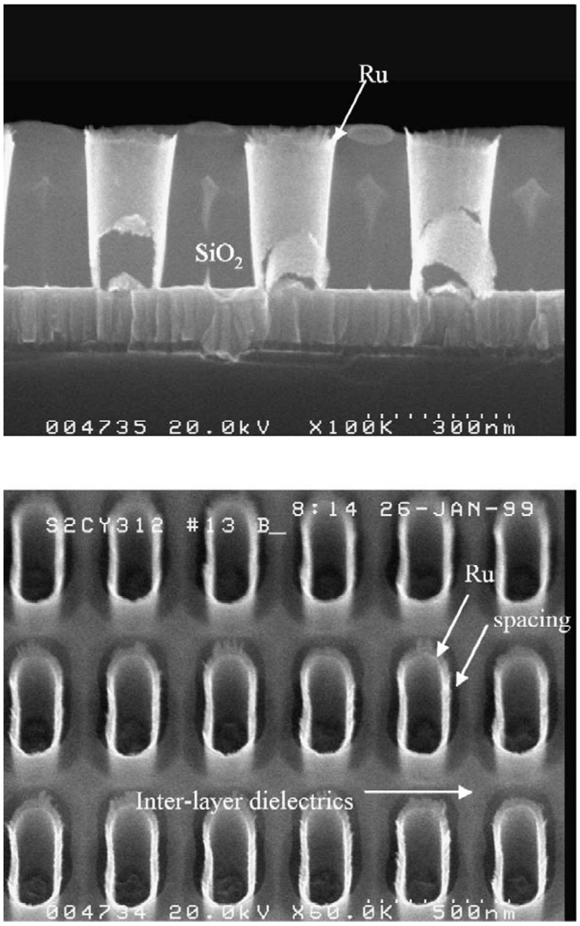

Fig. 5. SEM image of the concave-type structure with the cusped crown-shaped Ru after removing the HSQ with the HF solution.

top of the SiO_2 layer beneath the ARC layer. Fig. 6 shows the SEM image of the concave-type structure, revealing that the spacing between the Ru and the SiO_2 has been minimized due to the introduction of a blocking Ta_2O_5 layer. We subsequently deposit the BST layer and the top electrode Ru layer, forming the capacitor structure.

We have performed the electrical test with the concave structure with and without the cusped crown-shaped Ru structure. The test result indicates that the higher leakage currents were generated in the lower applied voltage when the top part of the concave structure is cusped crown-shaped (not shown here).

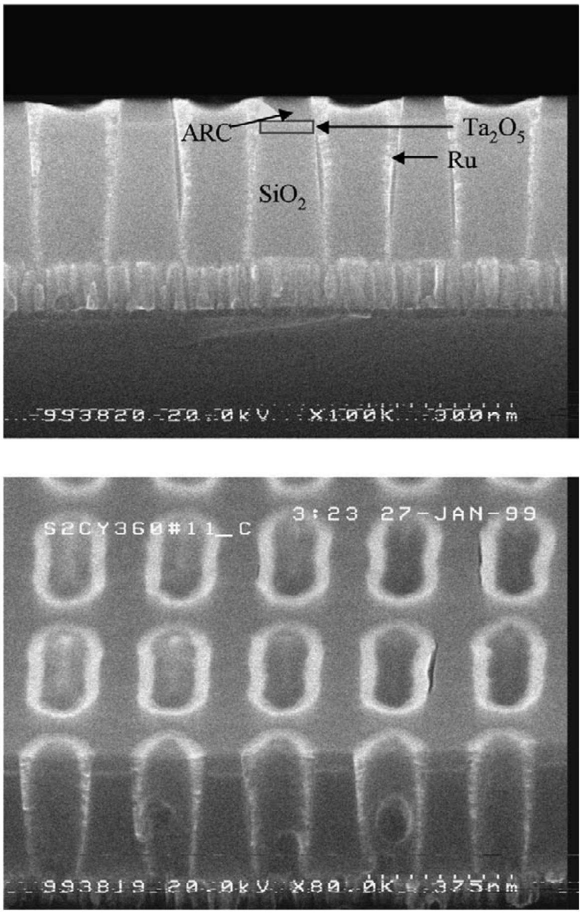

Fig. 6. SEM image of the concave-type structure after removing the HSQ with the HF solution. There is no spacing between the SiO_2 and the Ru, due to the insertion of a Ta_2O_5 layer.

4. Conclusions

To avoid the difficulties of high aspect ratio Ru etching, we suggest introducing a concave-type storage node pattern. We deposit the protective HSQ layer and then etchback is performed to isolate the Ru layer of each concave structure. The etch amount of HSQ etchback needs to be optimized to avoid the generation of a cusped crown-shaped structure of the remaining Ru.

Acknowledgements

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