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Selective etching of SiO_2 over Si_3N_4 in a $C_5F_8/O_2/Ar$ plasma

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Abstract

The self-aligned contact (SAC) oxide etching is a key process in developing the next generation ultra large scale integrated (ULSI) device because transistor gate feature size is scaling down, and aspect ratio is becoming higher and higher. In this study, the SAC etching will be characterized by $C_5F_8/O_2/Ar$ plasmas as a function of C_5F_8/O_2 gas mixing ratio, Ar flow rate, process pressure, and RF power. The oxide etch rate increases when C_5F_8 fractional flow rate increases from 38% to 62% and then abruptly drops at the C_5F_8 percentage above 62%. The selectivity of nitride to oxide and fluorocarbon polymer increased under the following conditions: high C_5F_8 flow rate, low Ar flow rate, high process pressure, and low RF power. However, when the ratio of O_2 increases in the C_5F_8/O_2 mixture, the amount of polymer decreases and the ability of contact etching increases. SAC patterned samples were characterized by top-down critical dimension scanning electron microscopy (CD-SEM) and transmission electron microscopy (TEM). To analyze the effect of C_5F_8/O_2 gas mixing ratio, we investigated the chemical species in the gas phase with optical emission spectroscopy (OES). The components and thickness of fluorocarbon polymer on contact surface, bottom and sidewall were investigated with transmission electron microscopy-element mapping system (TEM-EELS) and X-ray photoelectron spectroscopy (XPS).

Keywords: Self-aligned contact; Global warming potential; Low GWP alternative gas; Fluorocarbon film

1. Introduction

As ultralarge scale integrated (ULSI) devices are scaled down, highly selective SiO_2 etching processes are increasingly required. Silicon nitride is used a passivation layer that protects circuits from mechanical and chemical attack, or as an etch-stop layer, enabling the fabrication of certain damascene and self-aligned contact (SAC) structures. In SAC etching processes, high SiO_2 etch rate and high selectivity of SiO_2 over Si_3N_4 are required at the bottom of contact holes which have high aspect ratio [1–3]. Therefore, SAC etching is a key process in developing the next generation ULSI devices because transistor gate feature sizes continuously scale down, and conversely aspect ratios increase.

Furthermore, from a respect of alleviating global warming problems, the uses of perfluoro-compounds (PFCs) are going to be restricted due to their higher global warming potentials (GWPs) [4,5]. As an alternative to C_4F_8, C_5F_8 is proposed as a promising candidate because of its shorter atmospheric lifetime and smaller value of GWP [6]. However, C_5F_8 plasma provides a greater selectivity of SiO_2 over Si_3N_4 than C_4F_8 plasma [1,7–9]. Therefore, it is important to clarify the etching characteristics in their reaction mechanisms in the gas phase and on the surface.

In this study, we have studied etching of an SAC pattern by using capacitively coupled $C_5F_8/O_2/Ar$ plasmas. Systematic studies were carried out as a function of the etching parameters, including RF power, Ar flow rate and process pressure. Plasma diagnostics were performed by optical emission spectroscopy (OES) measurements. In addition, SAC patterned wafers were characterized using critical dimension scanning electron microscopy (CD-SEM) and transmission electron microscopy (TEM).

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2. Experimental details

On a 200 mm wafer, 440 nm thick boron phosphor doped silica glass (BPSG, oxide) was deposited using a plasma enhanced chemical vapor deposition (PECVD) and 200 nm Si_3N_4 (nitride) films grown by low pressure chemical vapor deposition (LPCVD) with SiH_4 were prepared, respectively. The etch rate and selectivities of non-pattern oxide and nitride were measured as a function of C_5F_8/O_2 gas mixing ratio with process pressure of 13 mTorr, RF power of 1000 W, bias power of 1300 W and Ar flow rate of 500 sccm. Semisysco smart-EPD™ system was used to check optical emission spectrum from the plasma as a function of C_5F_8/O_2 gas mixing ratio.

Selective etching of SiO_2 over Si_3N_4 process was performed using a capacitively coupled plasma etching system. This system has two RF powers, RF powered electrode of 60 MHz is directly coupled to the plasma and RF power of 2 MHz is applied to lower electrode for bias power. The surface analysis of polymer on nitride films etched in various C_5F_8/O_2 gas mixing ratios was performed by X-ray photoemission spectroscopy (XPS, Physical Electronics, Quantum-2000).

The pattern samples were prepared to have SAC structures which were used to check etch profile, top view, and composition of polymer. A stopper (spacer) film made of low pressure chemical vapor (LP-CVD) nitride with SiH_4 covers the gate structure (gate oxide/poly/WSi_x/hard mask nitride), and a BPSG layer to which the contact hole is opened was fabricated on the stopper films. Photoresist thickness for SAC etching mask was 430 nm and organic bottom anti-reflected coating (OBARC) of 60 nm thickness was used for photo mask process. SAC patterned wafers were characterized using top-down CD-SEM.

We investigated the thickness and elements of by-product deposited on patterned structure that is, on photo resist, at side wall (stopping nitride), on contact bottom using TEM-ELLS. For protection of polymer, all samples were covered with SOG (spin on glass) after SAC etching.

3. Results and discussion

Fig. 1 shows the etch rates of SiO_2 and Si_3N_4 and selectivities of SiO_2 over Si_3N_4 as a function of C_5F_8/O_2 mixing ratio in $C_5F_8/O_2/Ar$ plasmas. The other processing conditions are Ar flow rate of 500 sccm, process pressure of 13 mTorr, RF power of 1000 W, and bias power of 1300 W. The oxide etch rate increases when C_5F_8 fractional flow rate increases from 38% to 62% and then abruptly drops at the C_5F_8 gas mixing ratio above 62%. Accordingly, highly selective etch oxide-to-nitride is attained at a $C_5F_8/(C_5F_8 + O2)$ of 62% because nitride etch rates gradually decrease with increasing C_5F_8/O_2 flow ratio. It is reported that selective etching of oxide-to-nitride using various CF_x plasmas is related to not only the radical flux in plasma but also the thickness of fluorocarbon film formed during the chemical etch reaction on oxide and nitride [10]. The C_xF_y layer plays a role as an inhibitor of the etch reaction stimulated by ion bombardment. Generally, the fluorocarbon film thickness on the oxide surface is less than that on the nitride, due to the liberation of oxygen from oxide which can easily remove CF_x species from the oxide surface [10]. Under low C_5F_8/O_2 gas flow condition, the low oxide etch rate indicates that the incident flux of fluorine was not enough to contribute to the oxide etching. In contrast, the etch rate of nitride film forming a thick polymer is accelerated by the supply of the O atoms, which consume the fluorocarbon film by the chemical reaction. With an increase of C_5F_8/O_2 gas mixing ratio, the sufficient ion flux promotes the etching of oxide on which a thin polymer is deposited but the nitride etching is suppressed by O_2 gas reduction, which results in producing a thicker fluorocarbon film. A critical gas mixing ratio, $C_5F_8/(C_5F_8 + O_2)$ of 62% in our experiment, may be dependent on the ion energy which passes through the CF polymer layer. Excess radical flux is supplied but the thickness of fluorocarbon film on oxide surface exceeds ion projection range, so that oxide etch rate is also reduced.

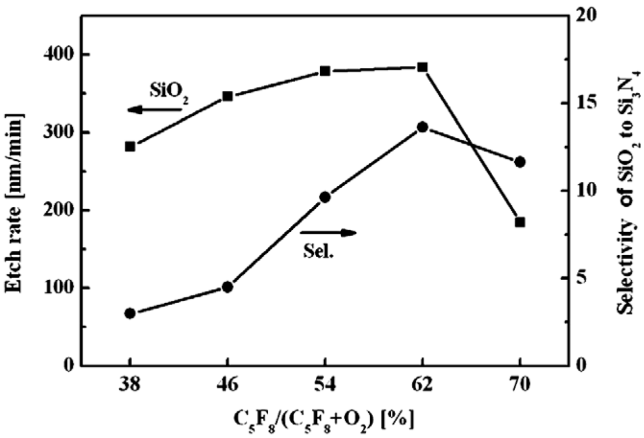

Fig. 1. Etch rates and selectivities of SiO_2 over Si_3N_4 as a function of C_5F_8/O_2 flow ratio.

Fig. 2(a) shows the SiO_2 and Si_3N_4 etch rates and selectivity of SiO_2 over Si_3N_4 as a function of Ar flow rate.

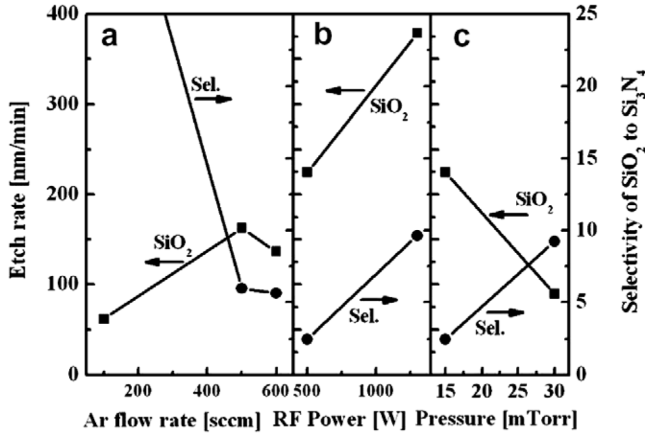

Fig. 2. Etch rates and selectivities of SiO_2 over Si_3N_4 as a function of Ar flow rate, RF power and process pressure.