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Etching optimization of post aluminum-silicon thermomigration process residues

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ABSTRACT

Al–Si thermomigration is an attractive means to produce through-wafer isolation walls for power devices. The unintentional layers of Al2O3 formed due to the necessary oxygen-containing ambient, after the thermomigration process, must be removed from the surfaces of Si wafer. In this regard, both dry and wet etching recipes are investigated in this article. Residues of Al2O3 and Al–Si alloy are eliminated without additional mask by a two-step etching process. BCl3 plasma treatment is proved to be effective to strip off the aluminum oxide layer with acceptable loss of silicon and silicon dioxide. Subsequent wet etching using commercial wet solution enables to remove the rest of Al-containing residues.

1. Introduction

Thermomigration (or TGZM for temperature gradient zone melting) is a unique mass transfer phenomenon caused by temperature gradient [1]. In semiconductor industry, thermomigration of aluminum in n-type silicon can be used as a doping technology to produce through-wafer isolation grids [2]. It enables to replace the conventional solid-state diffusion techniques and reduce the thermal budget of isolation process step by at least three orders of magnitude [2–4].

Decades of works have been performed to solve the remaining issues blocking the successful application of thermomigration to commercial power device processing [4–11]. Gas ambient control is found to be crucial in previous studies [11,12]. Oxygen-containing gas ambient is effective to prevent (i) the production of volatile silicon monoxide that pollutes furnace chamber and quartzware, and (ii) the evaporation and redeposition of aluminum during high temperature process. However, one associated problem with oxygen-containing gas ambient is aluminum-containing residue. At the beginning of the process, liquid aluminum reacts with oxygen forming aluminum oxide on entrance surface. The same reaction occurs when excess aluminum reaches the exit surface, yielding a sandwich structure of Al–Si eutectic alloy with a thin layer of aluminum oxide on its surface. Both the aluminum–silicon alloy as well as aluminum oxide must be removed to insure reliable electrical isolation.

Most of the groups [4,11,13,14] have adopted mechanical polishing methods to strip off residue of Al–Si alloy and Al_2O_3, however, this procedure may destroy previously fabricated structures (e.g. field oxide). An alternative approach to remove such surface contaminants is to selectively etch off the unwanted aluminum alloys and aluminum oxide. To date, traditional wet-chemical processes [12,15] (such as KOH, single or mixed acids solution), which are currently used in semiconductor industry, are impractical for the present work due to the high etching resistance and/or poor etching selectivity of aluminum oxide towards silicon and silicon-related materials. According to Lin et al. [16], by increasing the etching temperature (around 280 °C), the mixture of sulphuric and phosphoric acids is capable of patterning sapphire (α-Al_2O_3) substrate with silicon dioxide as a mask. This approach is probably an admirable solution to strip off Al_2O_3 as well as metal alloy without damaging silicon dioxide. Unfortunately, at such a high temperature, a specially designed facility is required to guarantee operation safety. To the best knowledge of authors, this kind of reactor has not been widely introduced in semiconductor production. As for dry etches, halogen plasma is commonly used to etch aluminum oxide [17]. However, previous studies [18,19] have shown aluminum oxide to be comparatively more resistant to dry etching than silicon, thus it has been generally proposed as a hard mask for the etching of silicon. Recently, it has been shown by Tegen et al. [20,21] and Bradley et al. [22] that by using specific combination of gases such as $Ar/C_xF_y/CH_xF_y/O_2$ or BCl_3/HBr, an acceptable selectivity of deposited aluminum oxide film to silicon substrate may be achieved. Nevertheless, those gases combinations are not widely available in commercial plasma etching reactors and Al_2O_3 layer formed during high temperature thermomigration process that seems to be more resistant in preliminary experiments.

In light of the limitations associated with these current removal methods, the present work aims to address a reliable approach to

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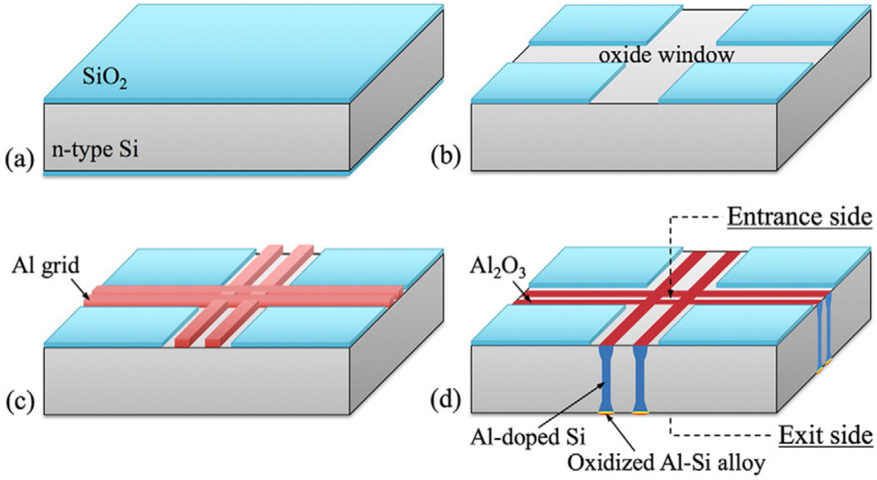

Fig. 1. Thermomigration process. (a) Oxidized n-type silicon, (b) open SiO_2 window, (c) aluminum pattern inside field oxide window, (d) thermomigrated sample.

entirely remove aluminum-containing residue after thermomigration process, meanwhile minimize the additional damage of silicon and silicon dioxide (SiO_2). The first part of this paper describes experimental details including wafer preparation as well as wet and dry etch recipes. Based on the etching data, we compare above etch recipes and a two-step etching process is then proposed and discussed.

2. Experimental

This study was performed with 6-in. n-type Si (100) wafers. About 1.2-μm-thick SiO_2 layers were thermally grown (Fig. 1-a) on both sides of the wafer. A network of SiO_2 windows was then opened on one side by conventional photolithographic techniques, while the entire SiO_2 layer on the other side was etched away by HF etching process (Fig. 1-b). Subsequently, 10-μm-thick aluminum film was deposited via vapor deposition, following second photolithographic process to pattern aluminum grid inside oxide windows (Fig. 1-c). After that, the thermomigration process was performed in a specially designed rapid thermal furnace with a mixture of O_2 and N_2 gases at 1300 °C during 3 min. More details about thermomigration process are described elsewhere [12,23]. For this study, 20 × 20 mm square samples were prepared from thermomigrated wafers and used for the following etching experiments.

Various wet-chemical recipes were tested, including phosphoric acid (85% H_3PO_4, at 160 °C), commercial mix of phosphoric acid, acetic acid and nitric acid (abbreviated as ANPE, 80:5:5:10 H_3PO_4 (85%): HNO_3 (70%): CH_3COOH (99%): H_2O, at 80 °C), buffered hydrofluoric acid (abbreviated as BHF, 10:1 NH_4F (40%): HF (49%), at 20 °C), piranha solution (1:1 H_2SO_4 (96%): H_2O_2 (30%), at 120 °C) and OPD 4280 (developer of photoresist containing 2.8% tetramethylammonium hydroxide, at 20 °C). Etching time was lasted several hours except for BHF solution. Due to the fact that BHF is a known etchant of silicon dioxide [15], etching time is limited for 20 min maximum to prevent the overetch of SiO_2.

Dry etching experiments were carried out using a Corial 200IL inductively coupled plasma (ICP) reactive ion etching system. The ICP source was controlled by a 2 kW, 2 MHz radio frequency (RF) generator, while substrate bias was controlled separately by a 300 W, 13.56 MHz

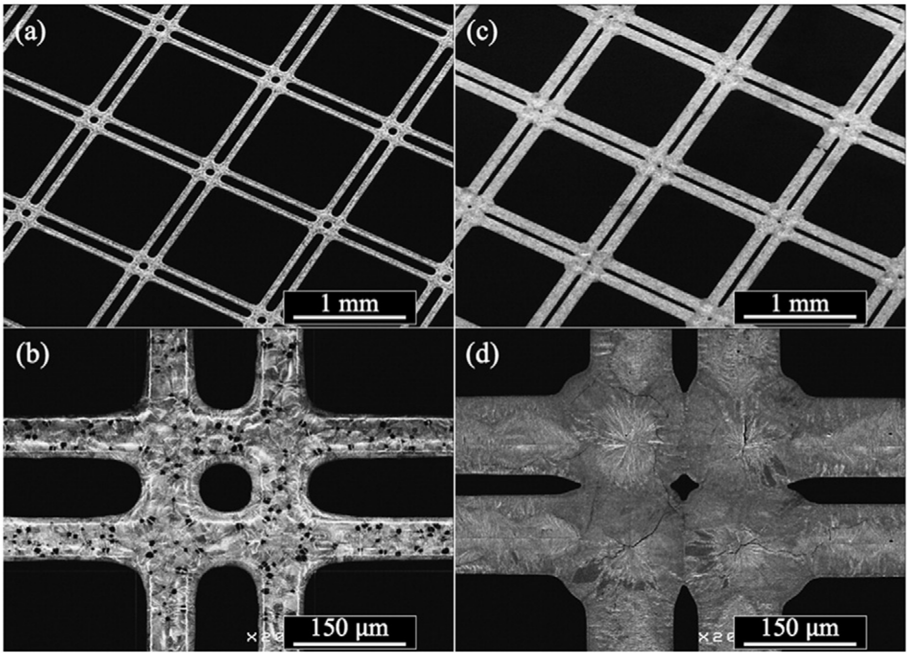

Fig. 2. Surface morphologies of entrance (a) and exit (c) surfaces after thermomigration process. Bright regions are covered by Al-containing residue. High-magnified views of the entrance (b) and exit (d) surfaces show the irregularity of thermomigrated region.