H_2 ANNEAL FOR SIDEWALL ROUGNESS REDUCTION IN INDUSTRIAL SETTING FOR MEMS MICROFABRICATION

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Abstract

The purpose of this paper is to illustrate hydrogen (H_2) anneal capability with the purpose to reduce Si surface roughness in MEMS microfabrication. This technique was successfully implemented and now being offered by C2MI fabrication facility in the sub-atmospheric vertical batch furnace on 200 mm wafers.

Introduction

Deep Reactive Ion Etch (DRIE) process, also referred to as a Bosch etch, is one of most commonly used technique in Micro-Electro-Mechanical Systems (MEMS) microfabrication. This technique creates the features with vertical side-walls and high aspect ratio, often essential in MEMS devices. The notable drawback of this technique is a sidewall roughness, formed with the cyclic etching and deposition steps, specific to the Bosch etching process. Sidewall scallops created during DRIE become a significant issue in some application, e.g. creating a scattering loss in optical waveguides. Smaller the waveguide dimensions, more impact the sidewall roughness is going to have on the scattering loss, [1].

Problem statement

One of the methods to improve sidewall roughness profile is to grow a sacrificial thermal oxide. With many benefits, there are notable limitations to this technique, i.e. depending on the size of these scallops and dimensions of the waveguides, thermal oxidation may be impossible to implement. Since the thermal oxide consumes the structural Si, its effect on the overall feature dimensions as well as the residual stress in some features could be detrimental.
Silicon atoms migration, which occurs in hydrogen (H_2) ambient at high temperatures, offers an excellent alternative to the thermal oxidation [2]-[5]. Silicon surface undergoes the minimal surface energy transformation under the influence of low pressure and high temperature in H_2 ambient. Based on the requirements and the process parameters, Si atoms migration can lead not only to roughness smoothing but also to certain degree of shape control in Si structures [6]-[8]. Considering the well-documented success of hydrogen anneal technique, this fabrication method is still not commonly used in MEMS manufacturing. Main drawback in the reported cases is that this anneal is done in a single-wafer equipment [2]-[8].

C2MI's solution

C2MI has developed a roughness smoothing technique in a batch-processing vertical furnace with high throughput and well-controlled reproducibility.
For this process, an SPT Microtechnologies RVP-9200 vertical furnace was adapted to work in a hydrogen ambient. A set of tests was conducted in this furnace to evaluate the followings: temperature, pressure, gas

flow, dwell time, and ramp-up parameters. These evaluations resulted in a set of parameters allowing a successful sidewall smoothing of test features on 200 mm wafers with maximum fill of furnace of up to 100 wafers at a time.

Results from one of these batch processing tests may be seen in the images of Figure 1, illustrating the reference wafer feature before the anneal (Fig. 1a-b) and the test wafer after the anneal with a complete furnace fill (Fig. 1c-d). The scallop smoothing was successful for the tests on single wafer processing as well as the fully filled furnace and for scallops sizes ranging from 10-50 nm through ~400 nm and up to ~1.0 µm.

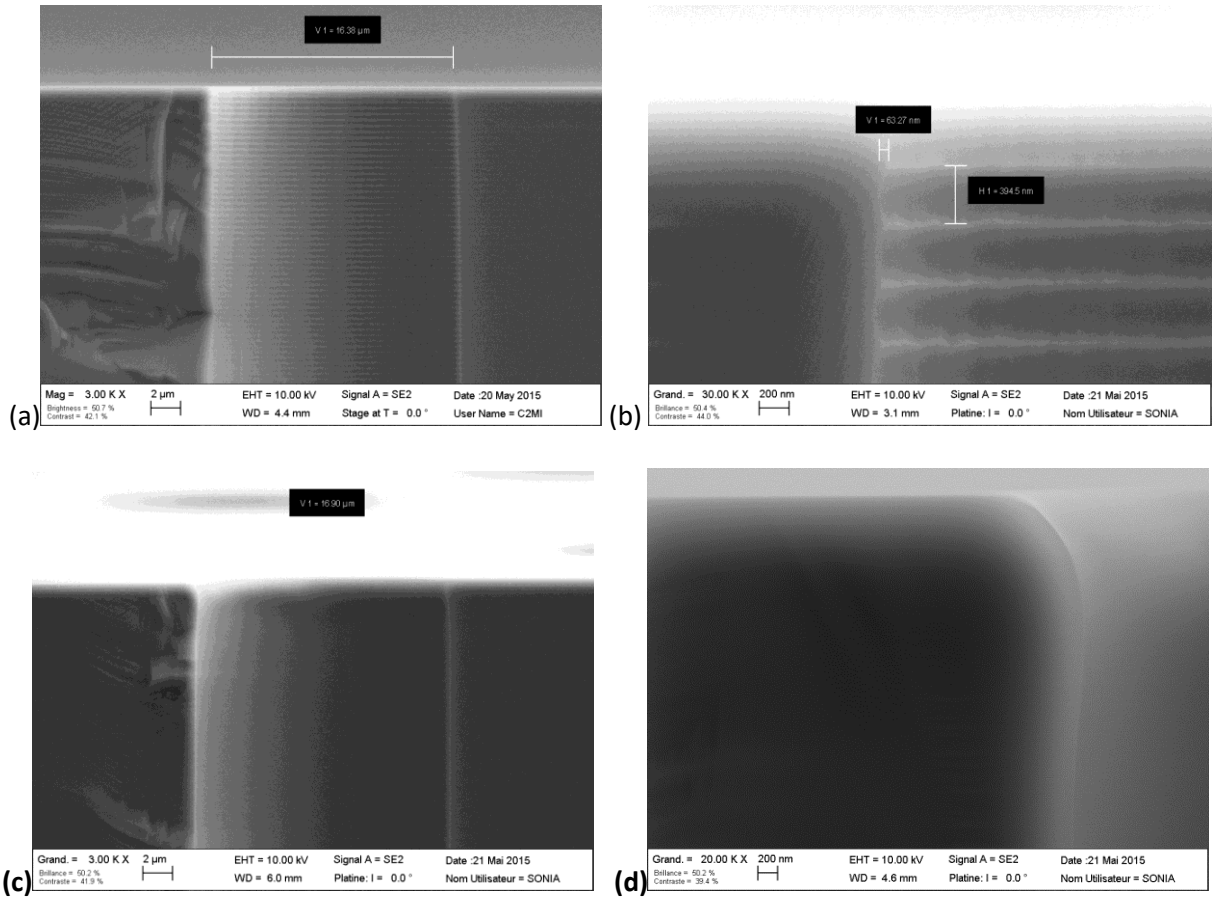

Figure. 1: SEM cross-section image of via side-wall profiles illustrating (a) reference wafer after DRIE, (b) reference wafer via close-up on the scallop size, (c) via x-section view after H_2 anneal, and (d) close-up on the via after H_2 anneal in the batch processing vertical furnace

Important part of the surface roughness smoothing is the wafer surface preparation. Prior to the hydrogen anneal, test wafers are prepared in an Akrion wet processor using wet chemistry tailored to the surface preparation. This step proved to be crucial in success of the furnace anneal.

Significant number of tests conducted through the years in C2MI's facility helped building an expertise in H_2 anneal process. The success of the process depends on type of features, features dimensions, roughness size and amount of Si requiring surface planarization. Customized H_2 anneal recipes can be created to suits product-specific requirements.

Summary

Analyzing few years worth of experimental data, C2MI can offer for the first time, and to the author's best knowledge, a successful sidewall roughness smoothing in a batch vertical furnace with well-defined parameters for large scale manufacturing. The same level of scallops smoothing is achieved with single wafer as well as complete furnace fills for the specified features in the test wafers; thus, proving that sidewall smoothing with hydrogen anneal can be implemented as a batch processing step in MEMS manufacturing.

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