G Model
PRE-6626; No. of Pages 6

ARTICLE IN PRESS

Precision Engineering xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Original research paper

Reducing edge roll-off during polishing of substrates

Urara Satake, Toshiyuki Enomoto*, Yuma Obayashi, Tatsuya Sugihara

Department of Mechanical Engineering, Graduate School of Engineering, Osaka University, 2-1, Yamada-oka, Suita, Osaka, 565-0871, Japan

ARTICLE INFO

Article history:
Received 19 July 2017
Accepted 27 July 2017
Available online xxx

Keywords:
Polishing
Polishing pad
Flatness
Edge roll-off
Substrate
Silicon wafer

ABSTRACT

Demand for reducing edge roll-off during polishing of substrates such as silicon wafers and glass disks has currently exceeded the capabilities of existing technologies. To address this problem, in previous studies, we have proposed that the use of double-layered polishing pads with a thin upper layer can reduce the edge roll-off of workpieces, resulting in improving surface flatness near the workpiece edge. However, such polishing pads have serious problems for practical use. In this study, we investigate the polishing factors required to suppress the concentration of contact stress near the workpiece edge. Based on the results, we propose two types of polishing pads and a polishing condition. Polishing experiments on silicon wafers reveal that the proposed polishing pads and polishing condition effectively improve edge-site flatness.

1. Introduction

Over the years, the semiconductor industry has continuously improved the performance of semiconductor devices while simultaneously reducing their price. To increase the integration density and productivity of these devices, the silicon wafers that serve as the substrates of the semiconductor devices must be extremely flat [1,2]. Currently, the global flatness across an entire wafer and the site flatness in a given area of a chip must be <100 and <20 nm, respectively [2]. In particular, there is a strong demand to reduce edge roll-off (ERO) during polishing, which is the final stage of wafer fabrication [2,3].

To meet this demand, several countermeasures to reduce ERO, such as the application of a retainer ring have been proposed [4] and put into use. In a previous work, we developed double-layered polishing pads with a thin upper layer [5]; using these pads, we achieved a very small ERO compared to the conventional approaches. However, the pads suffered from the following serious problems that interfered with their practical use because of the extremely small thickness of the upper layer:

- It is difficult to paste the thin upper layer onto the lower layer in a practical manufacturing process, causing the pads to have a high production cost.
- Grooves for slurry supply cannot be formed on the pad surface.

In this study, we investigate polishing factors other than the thickness of polishing pads required to reduce ERO. Based on the results, we develop two types of polishing pads and a polishing condition that are optimal for reducing ERO. We also evaluate the corresponding polishing performance of the proposed pads and condition.

2. Anisotropy of Young's modulus of polishing pads

The profile of the material-removal rate on the workpiece surface is proportional to the distribution of the contact stress between the workpiece and the polishing pad. Contact between the workpiece and the polishing pad can be modeled as contact between a highly rigid plate and an elastic body. Applying elastic contact theory to such a model shows why stress concentrates at the workpiece edge [6], thus leading to ERO during polishing.

According to the elastic contact theory, a body with a small thickness, large Poisson's ratio and high anisotropy of Young's modulus leads to a decrease in the contact-stress concentration in the contact model [7,8]. In previous studies, we employed finite element analysis (FEA) to verify how the polishing-pad thickness and Poisson's ratio affect stress concentration at the edge [5]. Next, we applied FEA (using MSC Software Corp., Marc 2014) to investigate the effect of the anisotropy of the Young's modulus of the polishing pad. In this study, we consider typical single-sided polishing (Fig. 1). The material properties and the dimensions of the workpiece and the polishing pad, which were determined based on the experimental polishing conditions (these will be described later), are listed in Table 1. A uniform pressure of 13.8 kPa was applied to the top surface of the workpiece.

* Corresponding author.
E-mail address: enomoto@mech.eng.osaka-u.ac.jp (T. Enomoto).

http://dx.doi.org/10.1016/j.precisioneng.2017.07.016

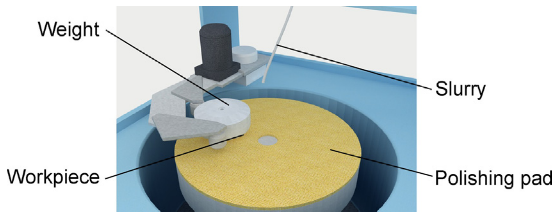

Fig. 1. Schematic of single-sided polishing process.

Table 1
Standard material properties and dimensions used in FEA.

	Diameter mm	Thickness mm	Young's modulus MPa	Poisson's ratio
Workpiece	125	0.7	193,000	0.35
Polishing pad	420	1.5	1.32	0.35

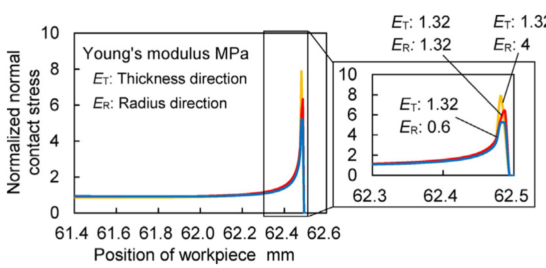

Fig. 2. Effect of anisotropy of Young's modulus of polishing pad on contact-stress distribution.

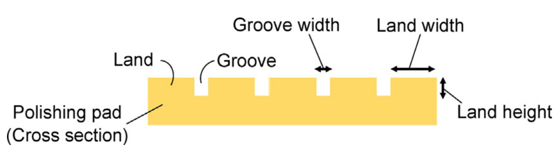

Fig. 3. Schematic of grooves on the surface of a polishing pad.

Table 2
Polishing conditions.

Polishing machine	Single-sided polishing machine Lapmaster SFT Corp., LP-15F
Workpiece	5-in. silicon wafer
Diameter of pad	420 mm
Polishing pressure	13.8 kPa
Rotation of workpiece	40 rpm
Rotation of pad	40 rpm
Stock removal	25 μm
Slurry	Colloidal silica (0.9 wt%) Fujimi Inc., GLANZOX-1302 (35 nm)
Slurry supply rate	25 mL/min

Fig. 2 shows the calculated contact-stress distribution in the radial direction near the workpiece edge. The results confirm that in each case, the contact stress was concentrated near the edge, leading to ERO, and a pad with a more anisotropic Young's modulus (i.e., a smaller Young's modulus in the radial direction of the pad, E_R, than in the thickness direction, E_T) was effective in decreasing contact-stress concentration. Then, we fabricated polishing pads with highly anisotropic Young's modulus by introducing grooves (Fig. 3) with extremely large land-aspect ratio (i.e., a small land width combined with a large land height) on the pad surface. Polishing experiments were performed to investigate the effect of the large land-aspect ratio of grooves on the ERO of a workpiece under the polishing conditions listed in Table 2. 5-in. silicon wafers were polished by colloidal silica slurry using single-sided polishing machine, setting stock removal of wafer 25 μm. ERO was evaluated

Table 3
Groove dimensions of polishing pads.

	Groove width mm	Land width mm	Land height mm	Land-aspect ratio
Pad A	1	59	0.6	0.01
Pad B	1	19	0.6	0.03
Pad C	1	4	0.8	0.20
Pad D	1	2	0.6	0.30
Pad E	1	2	0.8	0.40

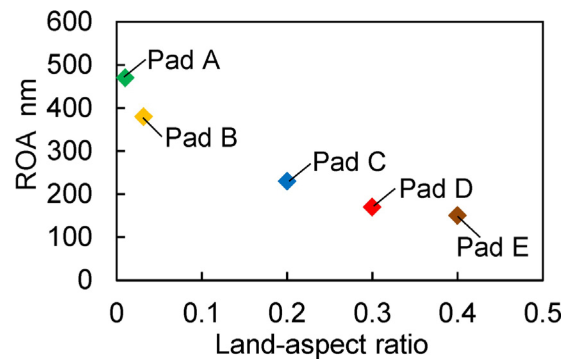

Fig. 4. Effect of land-aspect ratio of grooves on pad surface on ERO.

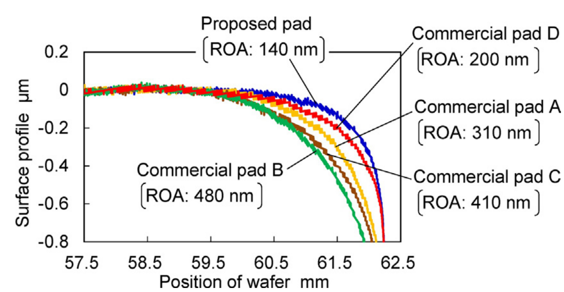

Fig. 5. Polished surface profiles near the wafer edge with the proposed polishing pad with highly anisotropic Young's modulus.

by defining the roll-off amount (ROA) as the vertical displacement from the level line to the measured wafer profile (e.g., see Fig. 5) at a distance of 1 mm from the periphery of the wafer. Five types of polyurethane foam-type polishing pads with latticed grooves having differing land-aspect ratios were prepared, as described in Table 3. Fig. 4 shows ROA value of wafer polished by each polishing pad. As shown in these experimental results, polishing pad with grooves with larger land-aspect ratio achieved smaller ROA value. The polishing pad with highly anisotropic Young's modulus attributed to the grooves with large land-aspect ratio was confirmed to reduce ERO effectively.

Based on the above findings, we designed a latticed-grooved polishing pad with a large land-aspect ratio (i.e., land width = 2.2 mm, land height = 1.0 mm, land-aspect ratio = 0.45) to obtain a highly anisotropic Young's modulus (base pad: Nitta Haas Inc., MH-S15A, polyurethane foam-type). Introducing grooves on the pad surface decreases the contact area between the workpiece and polishing pad, leading to greater settlement amount of workpiece to polishing pad because of increase in polishing pressure. A small groove width (0.3 mm) was adopted to suppress the increase in settlement amount of workpiece, leading to an increase in ERO. The reason for why greater settlement amount of workpiece enhances ERO will be described in Section 4. This proposed pad was used to polish silicon wafers under the conditions listed in Table 2. We prepared four types of commercial polishing pads (base pad: the same pad as the base pad of the proposed pad), which are generally used in practice, with grooves (commercial pads A–C) and without grooves