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Experimental investigation into Ball end Magnetorheological Finishing of silicon

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ABSTRACT

Ball end Magnetorheological Finishing (BEMRF) is a novel finishing process employed in the finishing of 2D and 3D surfaces. The magnetorheological effect imparted by the magnetic particles introduced through water or other carrier medium governs the finishing action of BEMRF. Abrasive and carrier medium play a vital role in the surface quality of the silicon material exposed to BEMRF process. In the present study, deionized water was used as a carrier medium while cerium oxide acted as an abrasive to finish the silicon wafer. An experimental study through statistical design of experiments were employed to predict the effect of process parameters such as core rotational speed, working gap, and magnetizing current on a percentage reduction in surface roughness of silicon wafer in BEMRF process. Individual effect on surface roughness values in terms of arithmetical mean roughness (Ra) was studied by applying ANOVA. The maximum contribution is made by the working gap on the surface finish was found to be the most critical aspect. Coming next was the magnetizing current while the last contribution was provided by the core rotational speed.

1. Introduction

Electronic, mechanical, and optical industries prefer, highly finished surfaces owing to their excellent properties [1]. Reduction of surface and subsurface damages on component surfaces, calls for a good to finishing of component under the moderate load conditions (with light forces). Also fine finishing of a component with close tolerances, demands precise control over the finishing forces, a situation that applies for all fine finishing methods. Consequently, many advanced finishing technologies such as magnetic field assisted finishing processes includes Magnetic abrasive finishing (MAF) [2], Magnetic float polishing (MFP), Magnetorheological finishing (MRF) [3], Magnetorheological abrasive flow finishing (MRAFF) [4], Magnetorheological Jet finishing (MRJF) [5], Magnetorheological abrasive honing (MRAH) [6], and Ball end Magnetorheological Finishing (BEMRF) were developed [7]. These finishing processes, enable external control of the finishing forces that act on the component surface. This is achieved by controlling the magnetic field strength through variations in the applied current.

Chemo-mechanical polishing (CMP) process has long been a chosen method in Si wafer manufacturing. CMP has the ability to finish silicon surfaces using polishing pad with abrasive slurry. The alkaline slurry used in CMP reacts with the surface and form silicates which enhances the surface finish quality [8]. However, the finishing forces in the CMP process are less controllable as they mainly depend on the polishing pad pressure. Hence, this process requires determinism in controlling the finishing action. MRF process uses the magnetically stiffened magnetorheological polishing (MRP) fluid to deterministically finish optically flat, spherical, and aspherical surfaces down to nanometres level [9,10]. The finishing forces in the MRF process mainly depend on the behaviour of MRP fluid as well as machining parameters such as rotational speed of the tool, working gap between workpiece surface and the tip of the tool, and applied magnetic field strength. The recently developed BEMRF has been capable of finishing 2D and 3D surfaces of magnetic and non-magnetic materials [11].

The MRF process was successfully applied for finishing a variety of materials including hard materials like WC–Ni composites, Al_2O_3-TiC, reaction bonded-silicon carbide and poly-silicon blanks [12,13]. Kyung-In Jang et al. [14] were studied the mechanism of material removal of electrochemomechanical Magnetorheological polishing process for finishing glassy carbon products. Kung-in Jang et al. [15] were proposed new deburring process in conjunction with magnetorheological fluid and this process applied successfully

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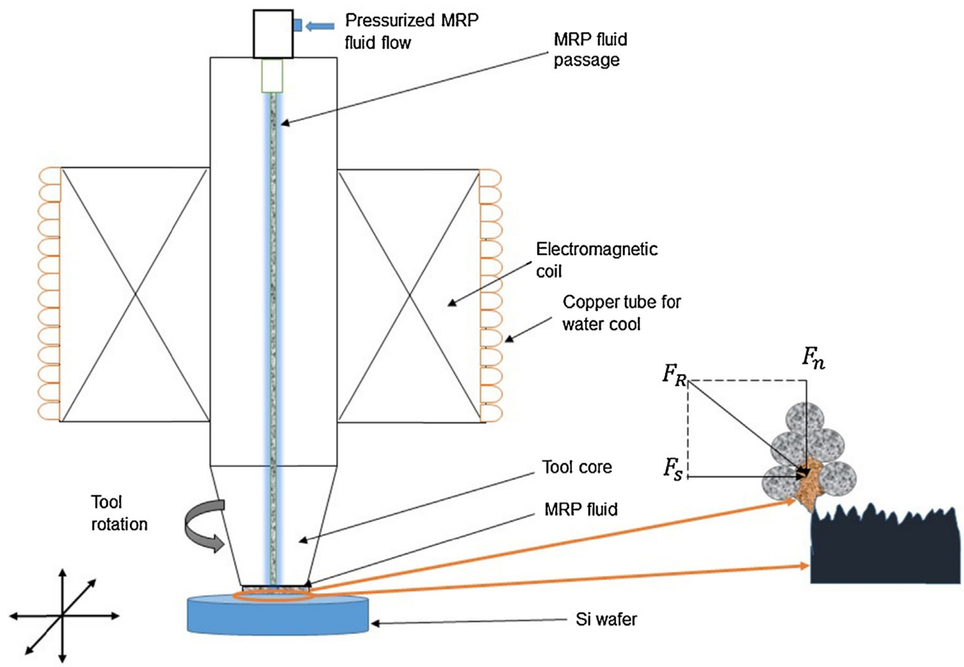

Fig. 1. Schematic Ball end MRF.

to remove metal burrs with a height of 200 μm and thickness of 1 μm in micro-moulds. Sidpara and Jain [16–18] developed and analysed the finishing forces in MRF process. They observed that normal forces are the predominant compared to the other forces.

A study of the effect of input parameters (fluid composition parameters and machine process parameters) of BEMRF process on the responses is essential to understand the surface finishing mechanism and for modelling the process. In this paper, an attempt has been made to comprehend the effect of machine process parameters such as core rotational speed, working gap and magnetic flux density on surface roughness of silicon wafer through statistical designing of experiments. Planning and analysis of the effect of process parameters on the percentage reduction in surface roughness (% reduction in Ra) have been undertaken by applying response surface methodology.

2. Magnetorheological polishing fluid

Magnetorheological polishing (MRP) fluid is a mixture of micron sized non-colloidal iron particles and abrasives that are dispersed in aqueous or non-aqueous carrier medium. These fluids are smart controllable fluids exhibiting unique, reversible rheological properties on application and removal of the magnetic field.

Considering its higher magnetic saturation and least cost, Carbonyl Iron Particles (CIP) was chosen for preparation of MRP fluid. High purity Carbonyl Iron particles are prepared from decomposition of pentacarbonyl iron which are also magnetically softer.

Sidpara and Jain [18] conducted an experimental investigation to study the effect of chemical interactions of abrasive and carrier fluid. Their study revealed that carrier medium play crucial role in polishing of silicon.

Type of abrasive plays a key role in finishing of brittle materials like glass and silicon. Cerium oxide is extensively used in glass polishing industry from several decades. Recent studies shows that CMP also utilizing ceria slurries for polishing silicon due to its chemical properties. Cook illustrated chemical tooth of cerium oxide and its strong interaction with silicate ions which promotes the removal mechanism in silicon based material removal process [19]. Ceria abrasive is also utilized for finishing silicon and other related silicate glasses in the MRF process [16,20–23].

Glycerol is used as stabilisers in water based MR fluids. Alkaline (viz. NaOH, KOH) helps to improve the stability and resistance to rust of the iron particles and also maintains the pH (strong influence on CMP of Silicon) of the MRP fluid [24].

3. BEMRF setup and experimentation

Schematic sketch of Ball end MRF tool is displayed in Fig. 1. In this process rotational speed was given to the tool while the feed rate (XY-movement) is given to the workpiece. The magnetic field at finishing spot was altered by varying the magnetizing current with variable regulated DC power supply. MRP fluid was injected through a fluid flow passage up to the tool tip surface. The slight magnetic field was applied (0.2 A current) for avoiding free flow from the tip of the tool. The tool was lowered towards the workpiece to set a gap between the tool and the workpiece. A spot size of 20 mm × 10 mm size was finished on 1″ diameter of 0.8 mm thick single crystal silicon wafer by giving Y-linear movement (velocity of 2.5 mm/s). Si wafer was fixed in a groove of 26 mm diameter and 0.5 mm deep of die steel circular blank (50 mm diameter and 5 mm thick) using paraffin wax and resin mix and then the circular blank was fixed on the precision vice. Each spot was polished for 60 min and after every 20 min MRP fluid is removed and fresh fluid was injected for exposing new abrasives in the finishing zone. The temperature was controlled throughout the experiment by a cooling electromagnet coil with constant lower temperature bath unit.

In this experimentation, fluid composition parameters such as CIP and abrasive size and their concentration, base medium concentration were kept constant while machine process parameters such as core rotational speed, working gap, and magnetizing current were altered. The experiments conducted revealed the best fluid composition for finishing the Si wafer is 25 vol% CIP, 6 vol% ceria, 2.5 vol% Glycerol, 0.75 vol% NaOH, and 66.75 vol% DI water. The present study employed the above fluid composition. Being water-based, small quantities of MRP fluid were prepared with the