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# Experimental and simulation study of nanometric surface roughness generated during Magnetorheological finishing of Silicon

Neha Khatri [a,b*], J.Xavier Manoj [c],Vinod Mishra [a,d], Harry Garg [a,b], Vinod Karar [a,b]

[a] *CSIR - Central Scientific Instruments Organisation, Chandigarh, 160030*
[b] *Academy of Scientific & Innovative Research (AcSIR), CSIR-CSIO, Chandigarh*
[c] *Anna University, Chennai*
[d] *Indian Institute of Technology, Delhi*

**Abstract**

Silicon Mirrors are essential components for guiding the X-Ray beam and focusing it to a particular location. These mirrors using total internal reflection require super smooth surface finish because X-Ray wavelength is very small, otherwise it suffers from strong scattering. The polishing possibility of silicon mirrors by Magnetorheological finishing process is examined. Magnetorheological finishing (MRF) is a computer-controlled technique that is used in the production of high quality optical lenses. This novel finishing process utilizes polishing slurries based on magneto rheological fluids, whose viscosity changes with the change in magnetic field. In this study, the MRF is used to polish the silicon mirror in order to achieve nanometric surface finish to be used for X-rays applications. The individual effect of parameters like magnetizing current, working gap, rotational speed on surface roughness is investigated. Based on the experimentation, the optimized process parameters are identified. The final surface roughness achieved is as low as 6.4nm. The surface quality is analyzed in terms of arithmetic roughness (Ra) and Scanning Electron Microscopy for uniform evaluation. In order to investigate the physical essence underlying MRF process, the Molecular Dynamics Simulations (MDS) is used. MDS is used to study the atomic-scale removal mechanism of single crystalline silicon in Magneto Rheological Finishing (MRF) process and particular attention is paid to study the effect of gap between the tool and work piece as well as cutting velocity on surface quality.
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*Keywords:*Silicon; Magnetorheological Finishing; Surface Roughness; Simulation.

* Corresponding author. Tel.: +91 7814047752;
*E-mail address:*nehakhatriuiet@gmail.com, nehakhatri@csio.res.in

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## 1. Introduction

Single crystal silicon is ideal optical material for infrared applications and other high added value products such as X-ray optics & X-ray interferometers. Silicon Mirrors are essential components for guiding the X-Ray beam and focusing it to a particular location [1]. These mirrors using total internal reflection require super smooth surface finish because X-Ray wavelength is very small, otherwise it suffer from strong scattering from surface [2] .Different shapes of mirrors such as flat, cylindrical, aspheric and ellipsoidal are generally used for focusing of X-rays. The advantages of mirrors include high beam throughput and no chromatic aberration compared to other focusing optics such as zone plates [3].

The conventional finishing processes like grinding, lapping, etc. are not capable to produce high quality surface finish. Therefore, some finishing operations are required to make the component suitable for desired function. One of the important aspects of finishing process is the precise control of the abrading forces so that the process produces the component with close tolerances [4, 5]. To overcome the limitations of conventional finishing processes, a number of finishing processes using magnetic fields have been developed [6]. Magneto-Rheological Finishing (MRF) is a novel polishing process that depends on smart fluid, known as Magneto Rheological (MR) fluid. The MR fluids consists of small micron sized magnetizable particles such as carbonyl iron, dispersed in a non-magnetic carrier medium like silicon oil, mineral oil or water. In the absence of a magnetic field, an ideal MR fluid exhibits Newtonian behaviour. When external magnetic field is applied, particles magnetize and acquire dipole moments proportional to magnetic field strength. When the dipolar interaction between particles exceeds their thermal energy, the particles aggregate into chains of dipoles aligned in the field direction [7].

The Magnetorheological finishing process is used by number of researchers worldwide to improve the surface roughness for various applications. Some studied the effect of process parameters to improve the surface quality in EN-31[8].Jain V.K. et al. experimentally investigated surface roughness and yield stress in MRF based Nano-finishing process to see the effect of process parameters with the help of the Response Surface Methodology. They developed a predictive model on brass and stainless steel for the surface roughness [9]. An experimental study on MRF has been carried out by Wan Li Song et al. in which magnetic field strength, normal load, and rotating speed are input variables and the surface roughness and material removal rate are considered as output variables [10]. In MRF process, the changes occur only a few atomic layers from the surface. In order to understand the mechanism of material removal, molecular dynamic simulation is appropriate method. A few MD simulations have been conducted to investigate the physical essence of the polishing process.MD simulations of polishing of a copper surface has been carried in Chemo-mechanical polishing to understand the fundamental mechanisms in terms of the nature of the material removal as well as the chip formation[11].

In this study, an attempt has been made to improve the surface finish with Ball End Magneto-Rheological Finishing process and to investigate the effects of parameters like current, gap and wheel speed on the final surface finish in silicon. Magnetizing Current, working gap and wheel speed are considered as input parameters; however, Surface Roughness considered as an outcome of the process. Molecular dynamics simulations is used to study the atomic-scale removal mechanism of single crystalline silicon in Magneto Rheological Finishing (MRF) process and particular attention is paid to study the effect of gap between the tool and work piece as well as cutting velocity on surface quality. The simulation results with a gap of 1.5 mm showed that a thick layer of silicon material is removed and an amorphous layer was formed on the silicon surface after rubbing. By contrast, the simulation results with a gap of 0.5 mm indicated that just one monoatomic layer of work piece was removed and a well ordered crystalline surface was obtained, which is quite consistent with MRF experimental results. The forces between abrasive particle and work piece is studied to account for the different removal mechanisms with gap of 0.5 mm and 1.5 mm.

## 2. Materials and Methods

### *2.1. Experimental Setup*

In Ball End MRF process, the tool is designed in such a way that the flow of pressurized MR fluid is through center of the tool core. Due to magnetic field, the fluid gets stiffened at the tip and ball end shape polishing spot is formed. The complete setup and process can be visualized as similar to ball end milling cutter 3 axis vertical CNC

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