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Study and Evaluation of parameters for High Finish of Germanium Substrates

Rashmi Singh
National Institute of Technical Teachers Training & Research
Chandigarh, India 160019

Harry Garg
Central Scientific Instruments Organization (CSIR-CSIO)
Chandigarh, India 160030

B.S.Pabla
National Institute of Technical TeachersTraining & Research
Chandigarh, India 160019

Rohit Sharma
Central Scientific Instruments Organization (CSIR-CSIO)
Chandigarh, India 160030

Prabhat Bhagel
Central Scientific Instruments Organization (CSIR-CSIO)
Chandigarh, India 160030

ABSTRACT

Optical material has increasingly been used for different applications due to its superior properties. The performance of these is affected by the polishing process and to achieve the better finish. Germanium has desirable properties such as light weight, good thermal conductivity, high strength,excellent infrared refractive index and has civilian applications. The polishing of the Germanium for high finish applications is challenging.

Conventional polishing is the most refined finishing processes which target the finest surface. There are different parameters (speed, load, abrasive concentration, pH) which effect the polishing process and it is often required to increase the polishing time in order to improve the roughness and maintain desired surface integrity. This work aims to study the surface roughness of Germaniumby conventional polishing. The DOE technique using Taguchi has been used to optimize the parameters. In this experiment, cerium oxide slurry with different concentration is used with deionised water to polish Germanium on a polyurethane pad. The result indicates that polishing on polyurethane pad with cerium slurry and speed of polisher spindle has significant effect on surface roughness.

General Terms

Ge- Germanium, MR/MRR- Material Removal/ Material Removal Rate, Ra- Average Surface Roughness, DOE- Design Of Experiment, L_9 orthogonal arrays, ANOVA- Analysis of Variance.

Keywords

Germanium, Polishing, Taguchi's method, Surface Roughness

1. INTRODUCTION

In the recent trends, Polishing of Germanium is tough deal due to its brittle nature. Many application of optical engineeringhave progressively been increasing, with greater demand of improving the finishing quality in the Germanium componentfor low optical scatter.Various techniques of polishing i.e. chemical mechanical polishing, float polishing, magneto-rheological polishing, and traditional polishing used for brittle material. Since Chemical mechanical polishing (CMP) processhas emerged as the solution for surface global planarization, and has been widely used for the manufacturing ofSemiconductor (Ge), hard disk, optical glass, etc.

The present study is to challenge the modern technology and achieve the better surface quality and low surface roughness.Three parameters particularly speed, abrasive concentration and load have been investigated in current work. In this work, surface roughness of a workpiece polished with a polyurethane lap during chemical mechanical polishing of pure germanium optical substrate were inspected, and defect-free optical workpiece were obtained.

2. LITERATURE SURVEY

Suratwala et al[1] shown in his studies about the deposition of slurry(Coagulation), spatial distribution and substrate deposition on the pad that can influence both the fine and mid-scale structure of material removal uniformity on the workpiece.Theyhas also formulated on the spatial and temporal [2] polishing model and used to simulate theexperimental data incorporating (1) the friction coefficient as a function of velocity (2) the relative velocity, which isdetermined by the kinematics of the lap and workpiece motions, and (3) the pressure distribution, which is shown to be subject by (a) moment forces, (b) lap visco-elastic, and (c)workpiece /lap interface mismatch. In his study**,** Wang et al [3] found that MRR increased from 250 to 675 nm/min as the concentration decreased 1 to 0.25 wt% in optical material. They used CMP method with ceria slurrieswithin an ultralow concentration below 1 wt. %. In a concentration of 0.25 wt. %, a MRR of675nm/min was achieved and a good surface with an rms 4.7A^o in a 1µm x 1µmarea was obtained. It was reported that the contact surface and the pressure distribution affect the substrate structure and frictional behaviour also effect the surface finish androughness during this process. Preston[4] first determined the correlation between MR/MRR with pressure and velocity shown in equation (1):

$$MRR=\frac{dh}{dt} = cPV \quad (1)$$

where P is the down pressure, V the relative velocity between polishing pad and optical material and c relates the coefficient reflecting the effects of other factors on MR/MRR, such as temperature, slurry pH, pad material, polished material and so on. Li et al [4] also worked out on the distributions of velocity and pressure over the wafer-pad interface and simulated. It is concluded that if the rotation rate of wafer is closer to that of polishing pad, the velocity distribution is more uniform overthe whole wafer-pad interface, while the wafer rotation rate is much different from that of pad, the MR/MRR gradually increases with the increase of distance away from the center of wafer. Pal et al [5] worked on the polishing of BK7 glass byapplying Taguchi's method to investigate the material removal and surface roughness using Full aperture polishing techniques. Abrasive concentration is observed to be one of the significant parameters in optical polishing process. H. H. K. Xu [6] tested the micro structural condition of the damageand the major factor of Sub Surface damage. By using scanning electron microscopy in his experiment, finds the grain structure, larger depth of cut, basically the influence of grain boundary micro fracture which proceeds for grain dislodgement process.V. H. Y. LO et al[7] planned Taguchimethod to resolve the optimal parameter sets for rough polishing of stainless steel. Surface roughness are observed by Perthometer, the value gained below 0.04µm. Landis[8]analyzed the effects of polishing pressure and velocity onmaterial removal rate and the combination of chemical or mechanical removal mechanisms. It was found that use of the over arm device on a traditional polishing system can drastically affect the pressure visible at the work piece.Gillman [9] studied about the bound abrasive polisher that has several potential advantages over loose abrasive processes with pitch or polyurethane lap for finishing of optics. Theseinclude the major factors like polishing efficiency, temperature stability, cost of consumables and compatibility with computer numerically controlled generating machines. N Desai[10] summarized some precision polishing/advanced surface finishing methods that implement precision fabrication of flats and spheres as well as more complex optics, such asaspheric and freeform shapes has been considered. By changing the laps from pitch to polyurethane pad and all, the surface quality achieved and the material removal rate upgrades.Zheng et al[11] found experimentally the effect of abrasive particle concentration on material removal rate(MRR), MRR per particle and the surface quality and showed that the MRR increases linearly with the increase of abrasive concentration and reaches to the maximum when the abrasive concentration is 20 wt.%, and then tends to be stable.To this end, themechanics of the polishing process and chemicaleffects in polishing will be reviewed to develop amodel for the polishing process [12].

A bulk of studies have been done by various researchersto studied the effect of parameter used for the fabrication and understand the mechanism of polishing to attaingood surface quality, but still it is big challenge to achieve.The focus of this study is to inspire interactionbetween the two communities and enhance the better finishedpart.

3. MATERIALS AND METHODS

3.1 Material

The work piece material used for the polishing process is Germanium substrate with circular shape of 25mm diameter is examined. It has high index of refraction, infrared optical material, and has wider applications in thermal imaging cameras, etc. Pure Germanium 99.9% is used for the current work with its physical properties shown in Table 1.

Table 1 Characteristics of Germanium

Specifications	Values
Symbol	Ge
Atomic Number	32
Atomic Mass	72.59 g.mol^{-1}
Density	5.3gcm^{-3} at 20ºC
Young’s Modulus	103GPa
Poison ratio	0.26
Infrared Refractive index	4

3.2 Polisher

The material used for the polishing is polyurethane pad with the round shape which is softer than the workpiece. The pad material is elastic and porous in nature.

3.3 Input Parameters

3.3.1 Speed:

The speed is major parameter which effects the material removal rate and surface roughness of the substrate surface. Three different levels with 30, 45, 60 rpm have been chosen for the study.

3.3.2 Abrasive Concentration:

Abrasive used is Cerium oxide (CeO_2) which is powder in form with the abrasive size less than 12µm and spherical in shape. It is mixed with known quantity of 100ml deionized water. In the experiment, three different abrasive concentrations i.e. 5.0%, 7.5%, 10% have been used.

3.3.3 Load:

It is observed that due to rigid load, it show the positive result that pressure will be extremely large near the boundary of substrate-pad contact area; thereupon, the MR/MRR will be fairly large relative to the other area of substrate-pad interface which show better surface finish and low value of surface roughness.

3.4 Design Of Experiment

Taguchi’s method has been used for design of experiment which is being widely used for optimizing the process parameters. In this study, Taguchi’s L_9 orthogonal array has been used to explore the relationship of Surface roughness value (Ra) with the process parameters. The control parameters are spindle speed (rpm), abrasive concentration (wt. %), and load(kg). Table 2 Polishingcontrol parameters and their three different levels used for the D.O.Epresent the Taguchi’s standard L_9 orthogonal array.

Table 2 Polishing control parameters and their levels for Taguchi experiment

Parameters	Symbol	Levels		
		1	2	3
Speed (rpm)	A	30	45	60
Load (level)	B	2	4	6
Conc (wt. %)	C	5	7.5	10

3.5. Experimental Details

Three numbers of cylindrical samples (diameter 25mm x thick 10mm) are blocked together on an iron tool using pitch. The blocked work pieces of germanium are lapped over theiron tool using melted pitch in proper order. Lapping process provides flat and uniform surface. Lapping is pre-polishing process which makes the work piece ready for use. Eachnumber of experimentshas been performed based on the set of parameters given in the design of experiment (DOE). Polyurethane Pad Polisher is used for polishing of Germanium sample and the work piece polished for first four hours (shown in Figure 1). Abrasive slurry was poured manually at constant intervals of time. Each operation is run for four hours at room temperature (22ºC) after which the surface is cleaned and the surface roughness is evaluated by using CCI Profiler.

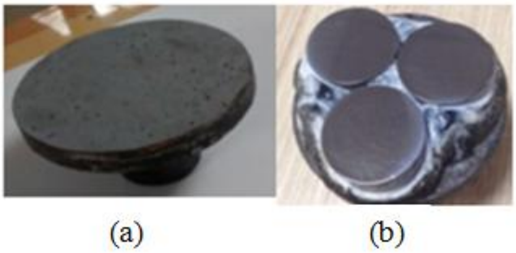

Figure 1: (a) Polisher of Polyurethane pad used for polishing; (b) workpiece surface after four hoursofpolishing.

4. RESULTS AND DISCUSSION

Average Surface roughness value is evaluated for the L_9polishing experiment conducted are shown in Table 3.

4.1. S/N Ratio Analysis

Signal to noise (S/N) ratios are used to evaluate the level of system performance.The method ofcalculating the signal-to-noise ratio depends on whether thequality characteristics has smaller-the-best,larger-the-betterornominal the best, this formulation was given byChen et al. [13].In the current work, S/N ratio for the condition “Smaller is better” is defined as:

$$\eta = -10*\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right),\ i = 1, 2, 3\ldots n, \qquad (2)$$

where n is the total number of experiments, $y_i$denotes the value of surface roughness for the i^{th} measurement.The best value of S/N ratios for lowest surface roughness (Ra) is achieved on the set of combination i.e. speed (60rpm), load (4kg) and abrasive concentration (5% by wt.) shown in Table 3. The obtained value of Average roughness (Ra) is 0.0061µm and the Signal to noise ratio is-15.8762.It can be inferred from the plots as shown in Figure 2 that the effect of different input parameterswith their levels on signal to noise ratio analysis for lowest surface roughness. Highest value of S/N ratios for average surface is observed for the sequences (A3B2C1) i.e. A3= speed, B2= load, C1= concentration. Signal to noise ratio identifies the value of roughness on the basis of the experimental data and the method used.

Table3. Experimental data based on DOE

No.of Experiments	Speed (rpm)	Load (level)	Conc.%
1	30	2	5
2	30	4	7.5
3	30	6	10
4	45	2	7.5
5	45	4	10
6	45	6	5
7	60	2	10
8	60	4	5
9	60	6	7.5

Table 3 shows that in Experiment no. 8with the combination A3B2C1 gives the optimal combination for lowest roughnessduring polishing process of germanium substrate.This combination gives the lowest value of Average roughness and smaller value of S/N ratios on the basis of Design of Experiment using L_9 orthogonal arrayafter doing the random experiment.

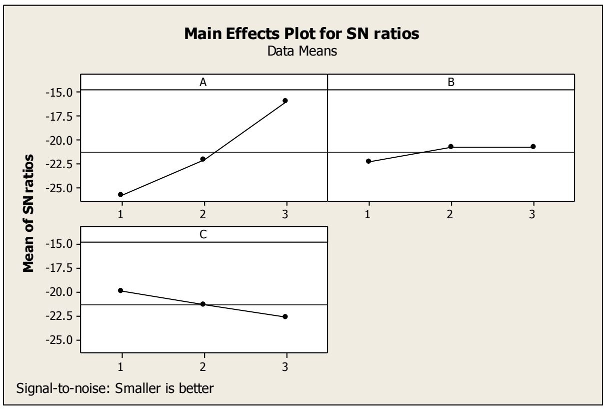

Figure 2 Main effect plots for Ra with the S/N ratios

Figure.2 shows the residual plots for Ra with the S/N ratios and shows their variation with the three parameters i.e. speed, load and concentration used in the experiment.The graph reveals that the mean of signal to noise ratio can be used to obtain the best combination for germanium polishing and better explain the surface roughness. The plot explains that the value of S/N ratio is smaller with the optimal combination of Spindle speed at level 3, Load at level 2 and Concentration at level1. Smaller the better value of S/N ratio gives the minimum value of surface roughness.

4.2 Analysis of Variance (ANOVA):

It is the statistical method nearly used to illustratethe experimented data and make decisions about the parameters under study. It helps to find the effect of each parameter used in the design of experiment and display among the better result for the surface roughness after the polishing of optical component.

Table 4 Analysis of Variance for Ra, using Adjusted SS for tests

Parameter	DOF	Seq. SS	Adj. MS	F test	%.Contribution
Speed	2	119.229	59.615	13.53	41.076
Load	2	65.47	32.735	7.43	22.555
Conc.	2	96.750	48.375	10.98	33.332
Error	2	8.810	4.405		3.0552
Total	8	290.259			

Table 4 shows the Analysis of Variance for the average surface roughness using F- test and percentage contribution of each parameter.From the ANOVA analysis, the spindle speed was observed to be the most important parameter affecting theresponse parameter i.e. Surface roughness. The percentage contribution ofspindle speed in the variance was computed as 41.07% for Ra analysis and 33.33 % contribution for abrasive concentration and lowest contribution for load obtained is 22.22% analysis. The F value (significance level) also indicated the significance of spindle speed over other factors. Abrasive size was observed as the next significant parameter, contributing above 20% in the total variance. The normal force/load was inferred to be the least significant parameter of all, owing to low value of F test and have contribution in the variance.

5. CONCLUSION

This paper presents an experimental investigation which attempts to gain a better scientific understanding of surface roughness through Conventional polishing process on Germanium optical component. Taguchi'sL$_9$configuration was used for the design of experiments. Following conclusions have been made based onexperimental results:

1. The lowest value of surface roughness and best surface finish was obtained for combination A3B2C1 (speed, load, abrasive concentration at different level) in polishing of germanium substrate using conventional polishing process.
2. It is inspected that spindle speed is one of the valid parameter in optical polishing that influence the final surface finish.
3. Abrasive concentration was also observed to be significant in determining the Surface finish, with smaller sized particles resulting in better surface finish.
4. 4.The best surface finish was obtained for parametric combination: A3B2C1.
5. The future scope of the present work is that polishing of germanium substrate can be widely used for IR applications with minimum surface roughness.
6. Most effect of Load/normal force acting on the interface of surface and polisher can be further investigated.

6. ACKNOWLEDGMENTS

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