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Evaluating Surface Roughness of Si Following Selected Lapping and Polishing Processes

Purpose

Lapping and polishing of samples is a common application and required for a variety of manufacturing and research processes. A wide range of techniques and methods can be implemented for any given polishing process and the type selected depends on the ultimate requirements of the sample. Surface finish, sample flatness and parallelism, and surface quality are all to be considered when selecting a polishing process. Each process type has different overall characteristics and can be of greater benefit depending on the final application of the sample. This report will demonstrate typical surface roughness measurements of silicon samples processed using different polishing techniques.

Materials and Methods

Sample Polishing

Lapping and polishing techniques can be divided into basically three types of processes: 1) Free abrasive on a hard lapping plate surface, 2) Fixed abrasive in the form of papers or films, and 3) Free abrasive on a cloth-like surface. All three of these methods are common in materials preparation and the selection of one process over another depends on the sample and application of the sample as well as user preference.

For this report several Si wafer pieces were obtained and cleaved into sections approximately $1cm^2$ x 700 µm in thickness. These samples were then mounted to a Model 150 lapping and polishing fixture for preparation. Each sample was processed using diamond lapping film down to 3µm using a Model 920 Lapping and Polishing Machine. This was used as the starting surface finish for all of the samples prior to processing for surface roughness measurements to ensure consistency in the process flow. Various processing times were used depending on the process selected. A basic illustration of the Model 920 using a Model 155 Lapping Fixture is given below.

Figure 1: Image showing the basic arrangement used for polishing samples. The Model 920 Lapping and Polishing Machine is used with lapping plates, abrasive papers, abrasive films, or polishing cloths for sample preparation. The Model 155 Lapping and Polishing Fixture is pictured as well, which is used for holding samples and controlling thickness during processing.

Several different samples were prepared for the surface roughness measurements using different abrasive media. The experiment is designed to show differences in roughness as it relates to sample processing techniques; therefore several samples were preparing using similar abrasive sizes combined with different methods to allow direct comparison of roughness. Below is a list of all of the samples and their processing techniques used for this evaluation.

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SAMPLE	ABRASIVE SIZE (µM)	PROCESS	TIME (MIN)
1	0.5	DIAMOND LAPPING FILM PROCESS	5
2	1	DIAMOND LAPPING FILM PROCESS	5
3	0.05	COLLOIDAL SILICA SUSPENSION ON MULTITEX™ POLISHING CLOTH	15
4	1	ALUMINUM OXIDE SUSPENSION ON MULTITEX™ POLISHING CLOTH	15
5	1	ALUMINUM OXIDE SUSPENSION ON RAYON FINE POLISHING CLOTH	10
6	1	DIAMOND SUSPENSION ON RAYON FINE POLISHING CLOTH	15
7	12	ALUMINUM OXIDE SUSPENSION ON GLASS PLATE	10
8	12	ALUMINUM OXIDE SUSPENSION ON CAST FE LAPPING PLATE	10
9	6	DIAMOND SUSPENSION ON SANYPOL POLISHING CLOTH	15
10	6	DIAMOND SUSPENSION ON CHEMOTEX POLISHING CLOTH	15
11	15	DIAMOND SUSPENSION (TYPE L) ON COPPER COMPOSITE LAPPING PLATE	10
12	3	DIAMOND SUSPENSION (TYPE L) ON COPPER COMPOSITE LAPPING PLATE	10
13	15	DIAMOND SUSPENSION (TYPE G) ON COPPER COMPOSITE LAPPING PLATE	10
14	3	DIAMOND SUSPENSION (TYPE G) ON COPPPER COMPOSITE LAPPING PLATE	10
15	1	DIAMOND SUSPENSION ON NYLON CLOTH (TYPE B)	15
16	1	DIAMOND SUSPENSION ON NYLON CLOTH (TYPE M)	15

Table 1: Table illustrating each of the samples prepared for the evaluation of surface roughness. Samples were processed using several different techniques to discover relationships between processing method and surface roughness.

Surface Roughness Measurements

Once the samples were processed and the surface was prepared, each sample was evaluated using the Dektak 6m surface profiler. This system is a stylus profiling instrument used for the measurement of surface roughness and other data as it relates to the sample. Stylus profilers are versatile measurement tools for studying surface topography. The stylus profilers rely on a small-diameter stylus moving along a surface either by movement of the stylus or movement of the surface of interest. A true stylus profiler moves linearly to obtain the measurement. As the stylus encounters surface features, the stylus moves vertically to measure various surface features, such as deposited film, irregularities, or finish [1].

Each sample was scanned after the polishing process to determine what the relative roughness was. The Ra and RMS was calculated using the instrument software package and was plotted and graphed as a function of the line scan taken.

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Results

All of the scans were taken using the same parameters as described in the section above. Roughness data were collected, giving the Ra and RMS both for each sample. A summary of the results is given in Table 2 below.

SAMPLE	RA (Å)	RMS (Å)
1	15	20
2	17	25
3	22	26
4	94	133
5	32	40
6	57	84
7	3140	4087
8	3382	4684

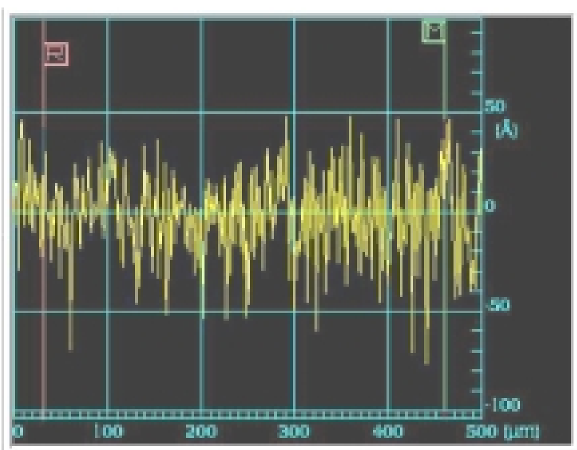
SAMPLE	RA (Å)	RMS (Å)
9	40	52
10	463	600
11	608	904
12	185	266
13	879	1239
14	195	253
15	24	30
16	23	29

Table 2: Summary of surface scan data giving the Ra and RMS values for each sample.

Diamond Film

Diamond lapping films are a type of fixed abrasive consumable that provides a high degree of flatness combined with excellent surface finishing properties and removal rates. Diamond films are commonly used in SEM and TEM sample preparation processes and therefore it is useful to note what type of surface finish these can produce. Two types of films were evaluated, 0.5µm and 1 µm, and are noted as sample 1 and 2, respectively. The surface profile images are given below.

From the scans it is clear that the surface roughness is much less than the particle size of the diamond film. 0.5 µm = 5000Å, but the surface roughness or Ra is 15Å, far better than what the diamond film should achieve. This shows the excellent finishing characteristics of these diamond lapping films. It is important to note that RMS is sometimes a better indication of the surface characteristics due to the measurement techniques employed.



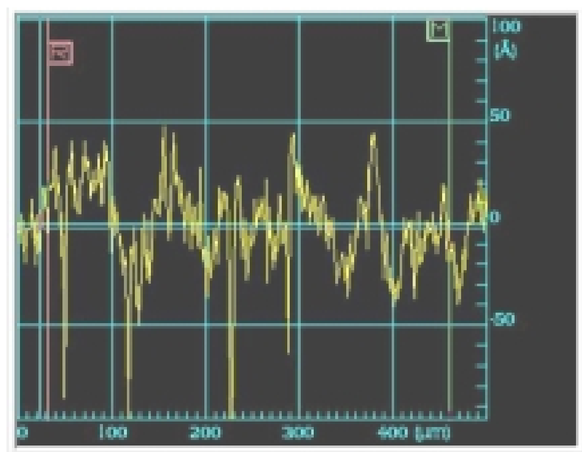


Figure 2: Surface profile scans of silicon wafer sample after polishing with 0.5µm (left) and 1 µm (right) diamond lapping films. The Ra was given as 15 and 17 Å, respectively.

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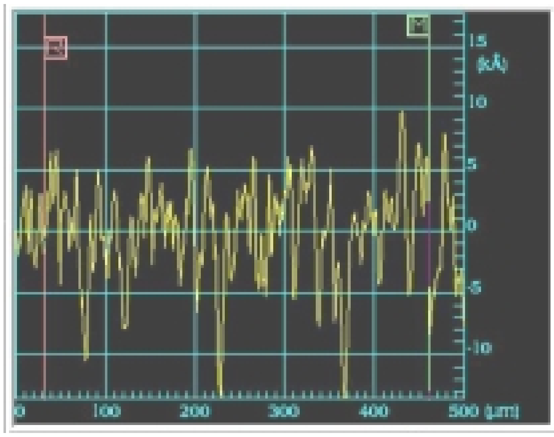
Free Abrasive Lapping on Plates

Lapping using a variety of lapping plates can create different surface roughness depending on the sample, lapping plate material, and abrasive media. For these experiments three different lapping plates were used to investigate the surface roughness: 1) Glass, 2) Cast Fe (iron), and 3) Copper composite. Aluminum oxide (Al_2O_3) and diamond suspensions were used for the investigation, and each roughness value was recorded following processing of the sample.

Aluminum Oxide Suspension

Aluminum oxide suspension of 12 µm particle size was used for lapping on the glass and cast Fe lapping plates. The Ra and RMS were found to be 3140Å and 4087Å for the glass plate and 3382Å and 4684Å for the cast Fe lapping plate. This shows that the glass plate produced an improved surface finish over that obtained with cast Fe. Figure 3 below shows the results obtained from these samples.



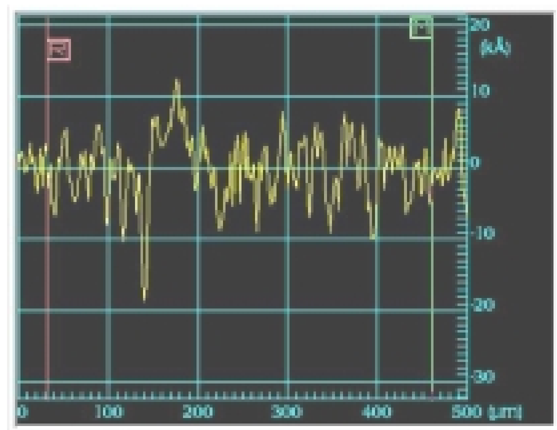
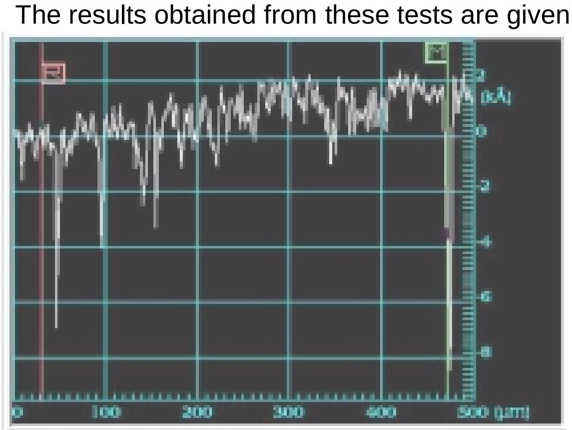


Figure 3: Surface profile scans of silicon wafer sample after lapping with aluminum oxide suspension on glass plate (left) and cast Fe plate (right). The Ra was given as 3140 and 3382 Å, respectively.

Diamond Suspension

Two different diamond suspensions were used for this investigation and were used solely on copper composite lapping plates. Two different abrasive sizes were used, 15 µm and 3 µm from two different manufacturers. This test was used to investigate the differences in surface roughness produced by both diamond suspension types and to compare (roughly) the surface roughness produced by the three different lapping plate types. The fine diamond particle size was used as a comparison to other techniques such as polishing cloth methods.

The results obtained from these tests are given in Figure 4 and 5 below.



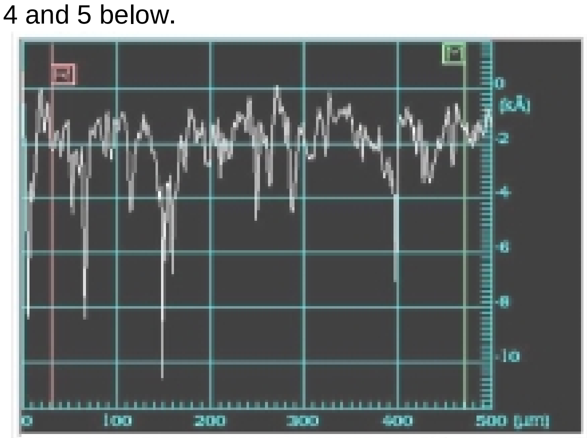


Figure 4: Surface profile scans of silicon wafer sample after lapping with diamond suspension on Cu composite plate using two different 15 µm diamond suspensions. The Ra was given as 608Å for sample 11 at left and 879Å for sample 13 at right.

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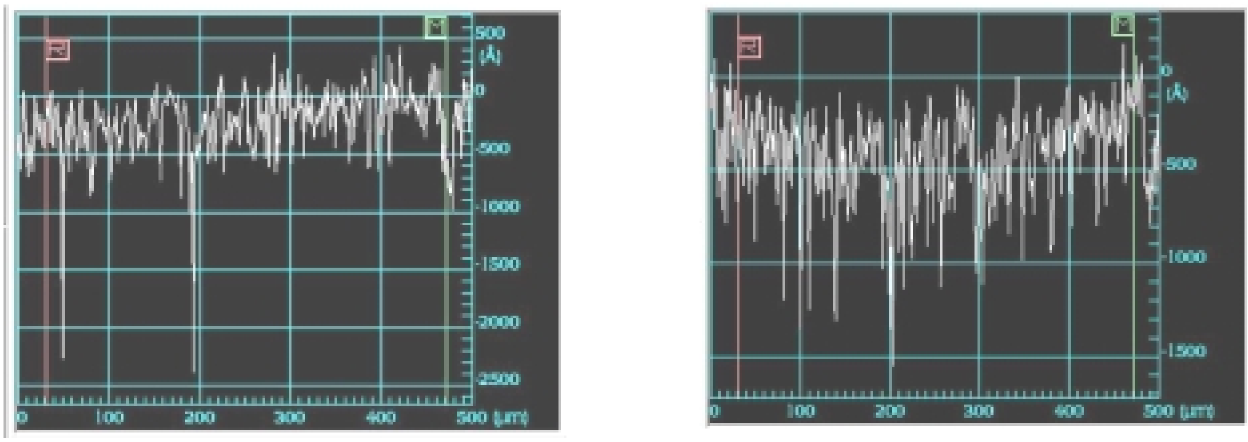

Figure 5: Surface profile scans of silicon wafer sample after lapping with diamond suspension on Cu composite plate using two different 3 µm diamond suspensions. The Ra was given as 185Å for sample 12 at left and 195Å for sample 14 at right.

Polishing Cloth

Processing samples using a polishing cloth process to produce smooth, relatively scratch free surfaces is a common practice in sample preparation processes. Several different abrasives and polishing cloths were investigated to determine what, if any, exhibited the best results from a surface finish standpoint.

Five different polishing cloths were investigated using the following abrasive types and sizes. This data is also listed in Table 1.

POLISHING CLOTH	ABRASIVE TYPE	ABRASIVE SIZE
MULTITEX™	COLLOIDAL SILICA	0.05 µM
	ALUMINUM OXIDE	1 µM
RAYON FINE™	ALUMINUM OXIDE	1 µM
	DIAMOND	1 µM
NYLON (TYPE B)	DIAMOND	1 µM
NYLON (TYPE M)	DIAMOND	1 µM
SANYPOL™	DIAMOND	6 µM
CHEMOTEX™	DIAMOND	6 µM

Table 3: Summary of polishing cloths and abrasives used for surface profile measurements.

6µm Diamond Suspension

Polishing cloths that provide a firm, hard backing are commonly used in 'rough' polishing processes, such as the 6µm phase of sample preparation. Two types of cloth were used to investigate surface roughness properties, the ChemoTex™ and SanyPol™ polishing cloths. Both were processed the same and surface profiles taken. The Ra values obtained were 463Å for the ChemoTex™ cloth and 40Å for the SanyPol™ cloth. This shows a dramatic difference in the surface finishing characteristics of these two cloths. Depending on what the final outcome of the sample is to be, it is clear that the SanyPol™ cloth provides superior performance when surface finish is concerned. Figure 6 shows the surface profile scans obtained from these two samples.

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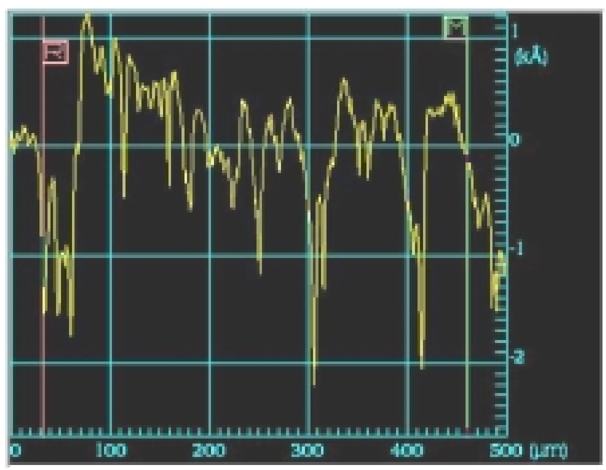


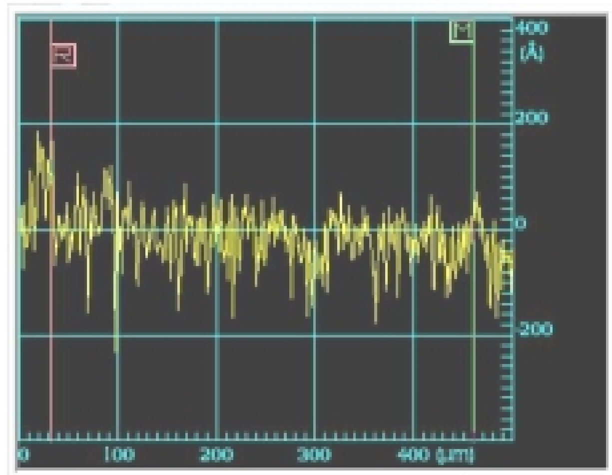
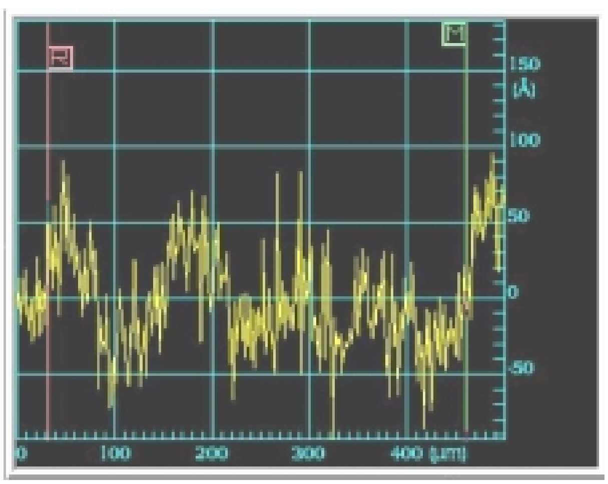


Figure 6: Surface profile scans of silicon wafer sample after polishing with 6 µm diamond suspension on ChemoTex™ (left) and SanyPol™ (right). The Ra was given as 463Å for sample 10 at left and 40Å for sample 9 at right.

1 µm Diamond Suspension

A fine polishing step around 1 µm is also a common preparation step and therefore is important to investigate the surface roughness obtained using different cloth types. For this investigation Nylon polishing cloth was used to evaluate surface roughness, along with Rayon Fine polishing cloth. Both of these are commonly used in fine polishing stages towards the end of the process. Ra values for the Nylon cloth were 24Å, while the values for Rayon Fine were 57Å. They Nylon cloth showed a more uniform surface with less variation in the scan, whereas the Rayon Fine cloth showed a greater deviation in the surface profile. Figure 7 below shows examples of the scans after processing was completed.



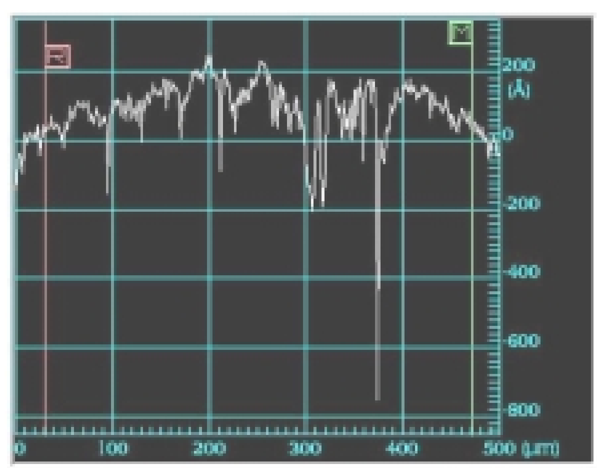


Figure 7: Surface profile scans of silicon wafer sample after polishing with 1 µm diamond suspension on Nylon (left) and Rayon Fine (right). The Ra was given as 24Å for sample 16 at left and 57Å for sample 6 at right.

1 µm Aluminum Oxide Suspension

As with diamond suspension, characterization of the surface finish using aluminum oxide must also be investigated. Aluminum oxide is often used in place of diamond as a final polishing solution that can be used for processing samples. Using the MultiTex™ and Rayon Fine polishing cloths, Ra values of 94Å and 32Å were obtained, respectively. This is an indication that the Rayon Fine polishing cloth provided an improved surface finish quality over that obtained from the MultiTex™ cloth. These results are somewhat surprising in that MultiTex™ is often used to produce a finely polished surface finish. Figure 8 below shows the results of these tests.

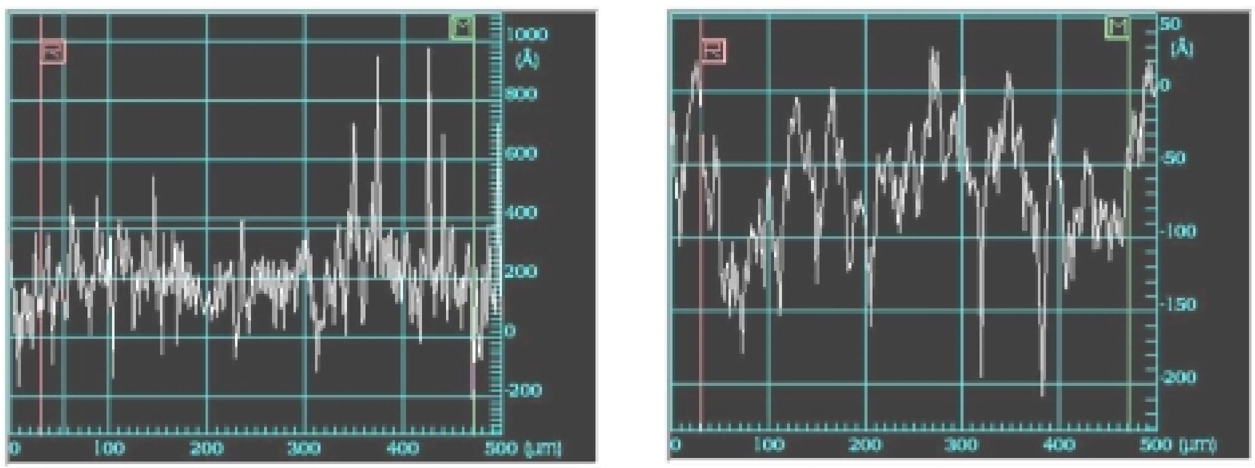


Figure 8: Surface profile scans of silicon wafer sample after polishing with 1 µm aluminum oxide suspension on MultiTex™ (left) and Rayon Fine (right). The Ra was given as 94Å for sample 4 at left and 32Å for sample 5 at right.

0.05 µm Colloidal Silica

As a final test, colloidal silica was used with the MultiTex™ polishing cloth to measure surface roughness as a function of this polishing solution. Colloidal silica is commonly used in final surface finishing processes and can be an excellent method of final polishing. Ra value of 22Å was obtained using this method. Figure 9 below shows results obtained from this polishing step.

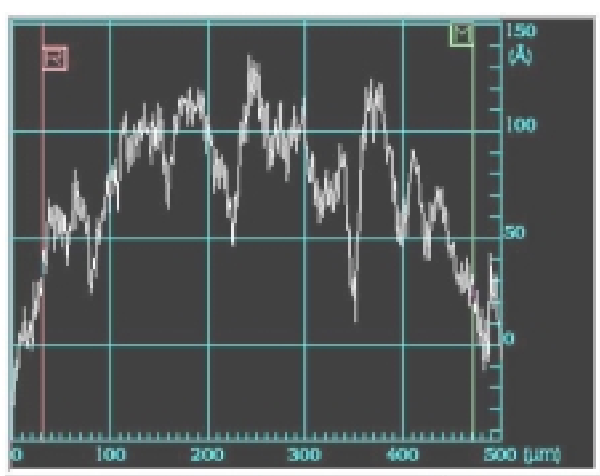


Figure 9: Surface profile scan of silicon wafer sample after polishing with 0.05 µm colloidal silica suspension on MultiTex™. The Ra was given as 22Å for sample 3.

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Discussion

From the surface profiles generated there can be some simple conclusions drawn as it relates to general sample preparation processes. Lapping of samples with a hard, metal plate is a common process that can be used in wafer thinning, wafer planarization, and optical component production. From the data, it is clear that the use of a Cu composite lapping plate arrangement offers superior surface finish as compared with other plates such as glass and cast Fe. The 15 µm and 3 µm stages showed good surface roughness compared with the other lapping plates.

Different polishing cloths produce varied surface roughness as well. Initial results showed a superior surface finish for a coarse abrasive size of 6µm produced with a SanyPol™ Medium polishing cloth as compared with the ChemoTex™ polishing cloth. Nylon polishing cloths also showed an improved surface finish for 1 µm abrasive as compared with Rayon Fine polishing cloths. MultiTex™ polishing cloths exhibited a surface roughness much higher than both Rayon and Nylon, which was somewhat surprising. These evaluations negate the effect of the optical quality of the surface, although it can be noted that all samples had a mirror-like surface finish from 3 µm abrasive size and below.

Finally, it was clear that diamond lapping films provide superior finishing properties. The surface finishing characteristics of diamond film processed samples showed good uniformity and the best surface finish as measured using the surface profiler. Although diamond films are excellent for SEM and TEM sample preparation they are somewhat difficult to use in wafer lapping and other similar applications due to the short lifetime and mounting techniques used.

Conclusion

Based on these experiments, a general sample preparation process can be determined for general wafer and similar optical lapping and polishing techniques. This procedure combines standard techniques of plate lapping and cloth polishing methods that have been in practice for some time.

1. Lap using a copper composite lapping plate and 15µm diamond suspension. Attainable Ra: 608Å
2. Polish using SanyPol™ Medium polishing cloth with 6µm diamond suspension. Attainable Ra: 40Å
3. If flatness is of primary concern, lap using a copper composite lapping plate and 3µm diamond suspension. Attainable Ra: 185Å
4. Polish using Nylon polishing cloth with 1µm diamond suspension. Attainable Ra: 24Å
5. For SEM and TEM samples, diamond lapping films are optimum for surface finish and flatness. Attainable Ra: 15Å

All of these data exclude the effects of colloidal silica polishing or finer abrasive media, however it can be used as a guideline in starting a process based on the surface roughness requirements. Surface finishes of reduced Ra can be attained by adjusting some parameters accordingly.

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2. Surface profile scans courtesy of T. Ballinger, Veeco.
3. Surface Metrology Guide: Profile Parameters. Downloaded from http://www.predev.com/smg/