ULTRA-PRECISION FLOAT POLISHING OF OPTICAL MATERIALS

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1. Introduction

The float polishing process has been originally developed for making ultra-smooth sapphire surfaces1) in order to develop the silicon-on-sapphire (SOS) devices. In this application, the substrates have to be dislocation- and contamination-free surfaces, however, the demand for flatness was not serious because of its application as a wafer. The next application was for making VCR magnetic heads of Mn-Zn ferrite single crystals2-3). In this application, the requirements of finished surfaces are higher flatness of λ/10 at 633nm wavelength, small surface roughness of less than 1nm Ry, sharp edges of 10nm radius at corners, dislocation- and elastic stress-free, though the samples were small. The residual elastic stress causes a change of magnetic property on Mn-Zn ferrite single crystal, and dislocation due to machining causes the broadening of the magnetic gap length. The magnetic heads for VHS high density recording were produced tens of millions in a year by using this float polishing technology, because this method can produce the ultra-precision parts in very high yield rate without skilled opticians.

Then, the float polishing has been used for making both ring laser gyroscopes and optics for high power lasers4) in industries and research institutes. This polishing method can make atomically flat surfaces on single crystals5-7) and optical glasses8-11) without subsurface damage. This technology can be also used for making flat on polycrystalline materials12-13), though there appear steps at the grain boundary due to the difference of removal rate on different crystallographic surfaces.

This paper deals with the method and some results on float polishing of optical materials for obtaining higher optical performance.

2. Polishing Procedure

The key technology of making flat surfaces by polishing is how to obtain and how to maintain a flat lap or polisher, so that opticians suffer troubles in flatness on pitch laps. The single point diamond turning of a tin lap is essential for float polishing. An ultra-precision float polishing machine8) like a double-column vertical lathe has a hydrostatic oil bearing of high rigidity and accuracy, and a rail head having a tool post. The tin lap of 460mm in outer-diameter and 120mm in inner diameter is set on the horizontal faceplate of the main spindle. The tin lap was fixed on a stainless steel plate by epoxy resin. At first, the tin lap was cut into flat by a sintered diamond tool and cut for making grooves of 1mm depth and width with a pitch of 2mm by a cut-off tool of high speed steel. Then the tin lap was cut flat by a sharp diamond tool of single crystal without any burrs, as shown in Fig. 1. The cutting conditions were 300rpm in revolution of the main spindle, 5μm in depth of cut and 0.3mm/rev in feed rate without lubricant. The lap was cleaned with pure water.

Pre-polished or ultra-precisely ground samples were fixed on a sample holder by low-melting point wax or by a double sticky tape. The polishing fluid was a mixture of pure water and 3wt% SiO_2 powder, and was controlled within a temperature range of 0.01K. Polishing pressure was only applied by the weight of the sample and sample holder. The rotational speeds of the lap and sample holder were 78rpm and Fig. 2 shows the state of float polishing of Si sample of 100mm in diameter.

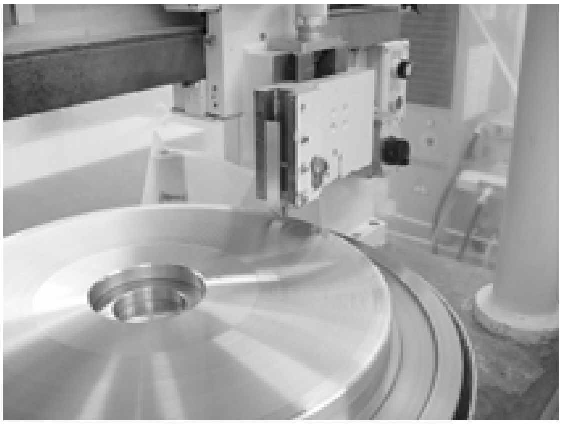

Fig. 1. Single point diamond turning of a tin lap.

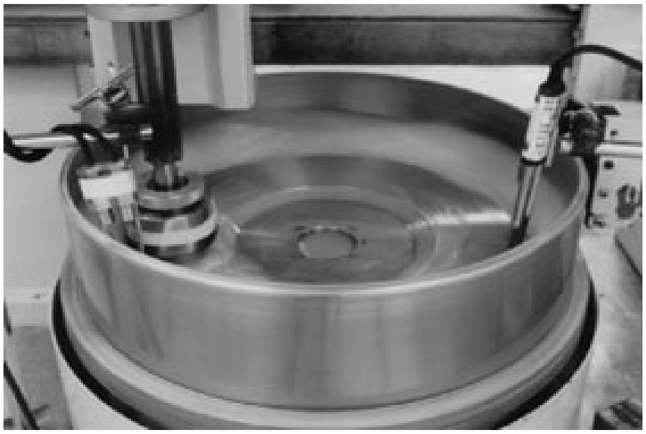

Fig. 2. The state of float polishing.

3. Optical Surface and Optical Properties

Figure 3 shows the flatness of a 100-mm-diameter, 20-mm-thick float-polished Si (001) sample, measured with ZYGO GPI-XP. The flatness was 28.4nm p-v, corresponding to $\lambda/22$ at λ =633nm wavelength, and 4.43nm rms. We also measured the surface roughness using a special scanning probe microscope (SPM) for large samples. The surface roughness values are 0.079nm rms, 0.063nm Ra and 0.59nm Ry, as shown in Fig. 4. Such surface roughness was obtained on various materials[5-7, 9].

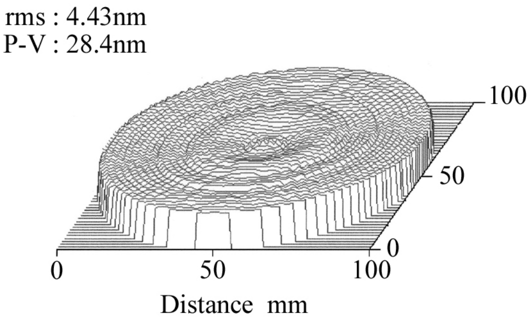

Fig. 3. Flatness of float-polished Si single crystal.

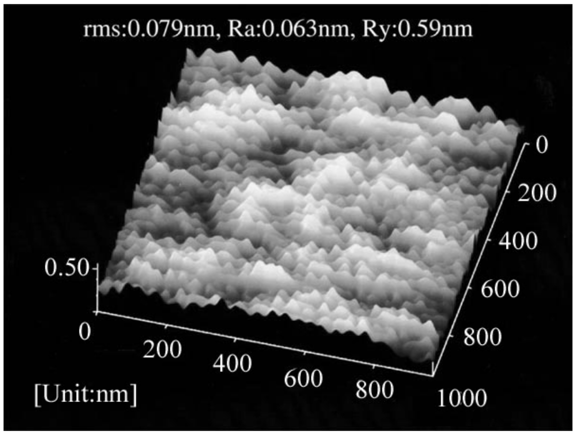

Fig. 4. Surface roughness of float-polished Si single crystal, measured with an SPM.

Figure 5 shows the relation between the specular reflectivity at the wavelength of 0.834nm on polished Si substrates and surface roughness at the grazing incident angle of 0.7 degree. In this figure the solid line shows the theoretical curve between the specular reflectivity and rms surface roughness on Si substrates. The specular reflectivity increases with the decrease of surface roughness even in the range of less than 0.5nm rms. The maximum sepecular reflectivity is calculated at 93.1% on the zero surface roughness Si. The measured specular reflectivity on the float-polished Si surface shows 91.2%, which is 98% compared with that on the ideal surface.

Figure 6 shows the relation between the laser-induced damage threshold on LHG-8 laser glass and surface roughness for several machining processes and laser irradiating directions. It is clear that the laser-induced damage threshold is a function of surface roughness. Float polished surfaces show the highest laser damage threshold of 31.9J/cm^2 as shown in Fig. 6, though the surface roughness variation is not so different among all the samples in the surface roughness range of less than 0.5nm rms. The reason of those differences is concluded that the float-polished surface is contamination free and also damage free.

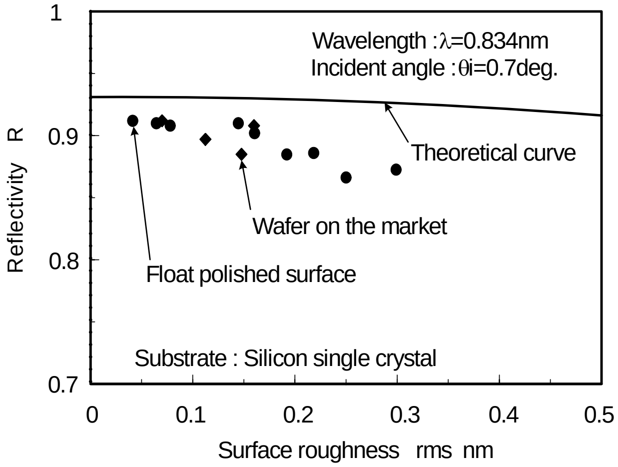

Fig. 5. The relation between the X-ray reflectivity and surface roughness on Si single crystal substrate at the wavelength of 0.834nm at the grazing incidence angle of 0.7degree[5].

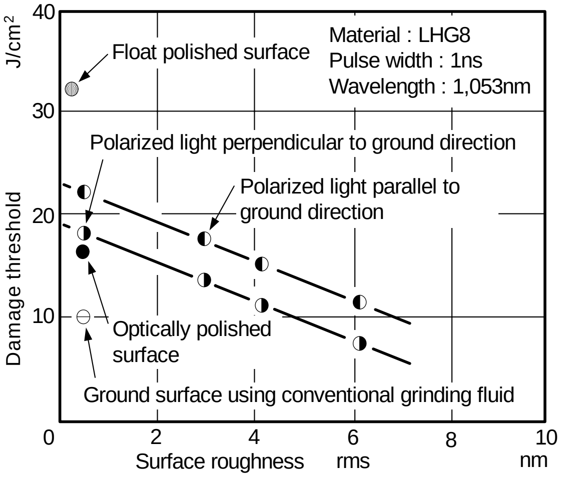

Fig. 6. The laser-induced damage thresholds of ground and polished laser-glass surfaces at the wavelength of 1053nm and pulse width of 1ns as a function of surface roughness[4].

The fracture strength of optical components is very important in space application as well as on the earth. The float-polished Zerodur glass-ceramics sample shows 4.7 times higher facture strength compared with the standard ground and polished samples[10]. In the case of quartz crystals, the float-polished samples showed 10 times higher fracture strength rather than conventionally prepared samples[6].

From the various surface analyses such as reflection electron diffraction, ion microprobe mass spectroscopy, Auger spectroscopy, etch-pit method and cross-section transmission electron microscopy, it was proved that the float-polished surface has no subsurface damage and no contamination.

4. Conclusions

The float polishing has succeeded in making extremely-smooth, damage- and contamination-free flat surfaces on single crystals and optical glasses. In some case, polished surface roughness shows almost same as ideal surface roughness. The problems to be solved in near future are float polishing of spherical or aspherical shape as well as polycrystalline and composite materials.

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