Research on Non-Cleanroom Micromachining and High Precision Surface Finish

Ultraprecision machining with well-defined diamond tools can provide a cost effective manufacturing platform for biomedical devices with micro- and nanoscale features. With materials like aluminum, brass and electroless nickel, true 3D microstructures with optical quality surface finish can be obtained by using proper machining process and machining conditions.

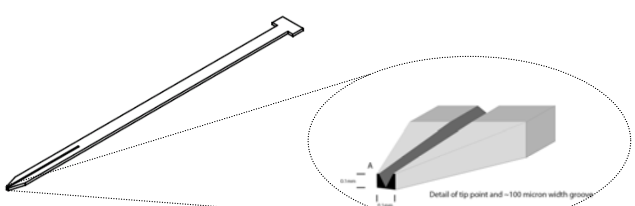
Noncleanroom Micro-/Nanomanufacturing

As part of NSEC Nanomanufacturing core technology group, our focus has been on providing the center with a low cost, short cycle time micro-/nanofabrication processing.

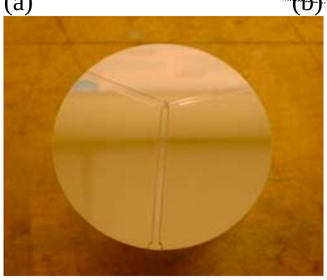
Affordable micro-/nanofabrication by microinjection molding and casting process

For commercialization, one important factor is achieving a fabrication process that is low cost with a short cycle time. For polymer-based biomedical devices, ultraprecision machining combined with microinjection molding and/or casting can fulfill this job.

Figures 1(a) and 1(b) show a microprinting tip design, which has a 100 μm V channel at the tip. Figure 1 (c) shows the aluminum mold insert for injection molding the part. The current process to fabricate this tip requires multiple cleanroom processes and would cost about $100 per piece. By using the injection molding process, the part can be manufactured at low cost with high precision. The aluminum insert was fabricated by using ultraprecision diamond turning and diamond milling processes to attain good surface finish and geometric precision. It is expected that a cost of <$1 per piece can be achieved by using this process. Moreover, an injection molded printing tip will have a much more complicated 3D structure, which would allow its functionality to be easily tailored in mold preparation.



(a) (b)



(c)

Figure 1. (a) Printing tip design close up; (b) view of the tip; and (c) the mold insert for injection molding process.

Figure 2(a) shows the design of a microtip used for bio spectroscopy. The internal through-hole on the very end of the tip has a 10 μm diameter opening. To fabricate such a microtip, a UV-cure-based casting process was chosen. A special mold structure was designed and fabricated on the ultraprecision machine.

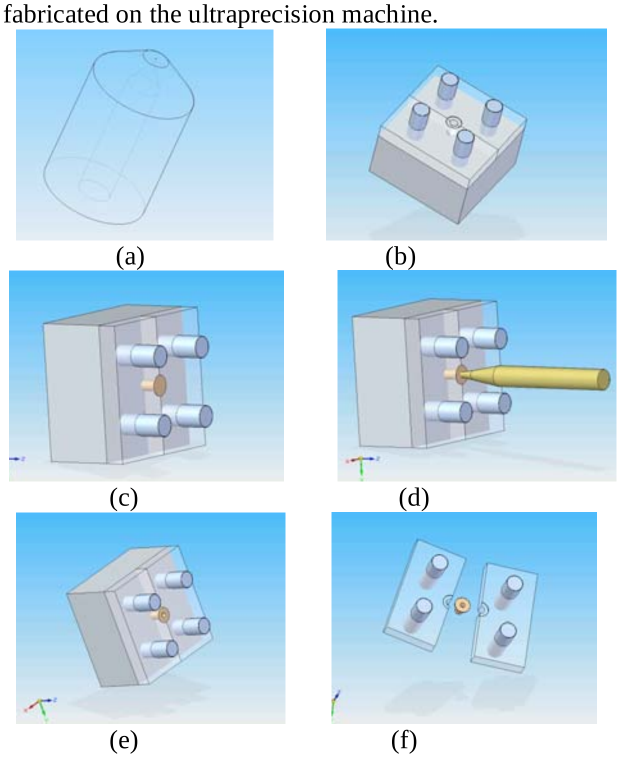


Figure 2. Design and casting process for micro nozzle tip. (a) Design of the tip; (b) structure of the mold; (c) filling and first step UV cure; (d) through hole molding and second step UV cure; (e) third step UV cure; (f) de-molding process.

Microstructure fabrication on hard materials

Microstructure fabrication on hard materials, such as glass, silicon, and stainless steel, was also tested. For micromachining on hard materials, a diamond grinding tool and ultra-high-speed spindle were utilized. Figure 3(a) is the SEM photo of the diamond grinding tool, and Figure 3 (b) is the SEM photo of the machined glass surface.

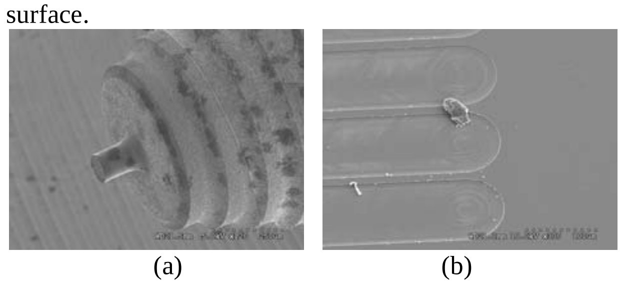


Figure 3. (a) SEM photo of a diamond grinding tool; (b) SEM photo of a machined glass surface

High quality surface generation by single point diamond machining

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A single-point diamond turning process has been used extensively for direct high quality optical surface fabrication. Compared with more conventional fabrication methods, single-point diamond turning can be used to produce high quality surfaces without polishing, which greatly reduces manufacturing cost. However, diamond turning involves many possible variations, such as machine tool performance, diamond tool condition, and material properties. More importantly, diamond machined surfaces have characteristic periodic tool marks.

We carried out this research to better understand the characteristics of the diamond machining process and diamond machined surface. In this research, the relationship between the machining conditions and machined surface quality (both optical scattering characteristics and the surface roughness) was studied, and the optimal machining condition was also analyzed. A number of experiments were carried out using different machining processes and different machining conditions. Both a Veeco NT 3300 surface profilometer and a home-built scattering device measured the characteristics of the machined surface.

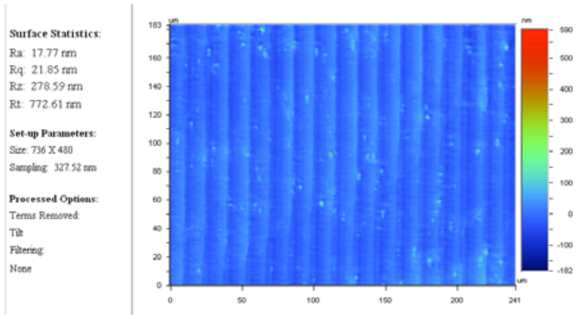

Figure 4(a). Surface profile of 15 μm cutting step sample

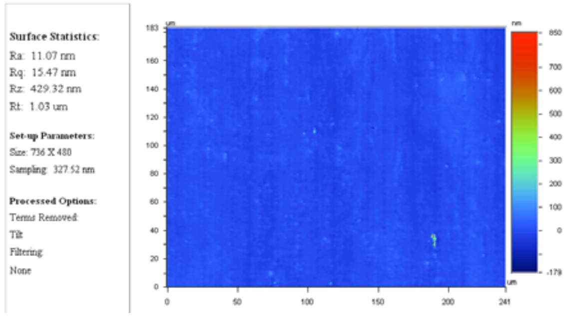

Figure 4(b). Surface profile of 4 μm cutting step sample

Figures 4(a) and 4(b) show the measured surface profile of the samples machined at 15 μm step size and 5 μm step size, respectively. The surface roughness of the first sample is 17 nm, and the surface roughness of the second sample is 11 nm. On the first sample, the tool marks can be seen clearly. Figure 4(c) shows the measured surface scattering of the 3 samples. For the 15 μm sample, the scattering is very strong, the 5 μm sample still has some scattering and the 2 μm sample has very weak scattering.

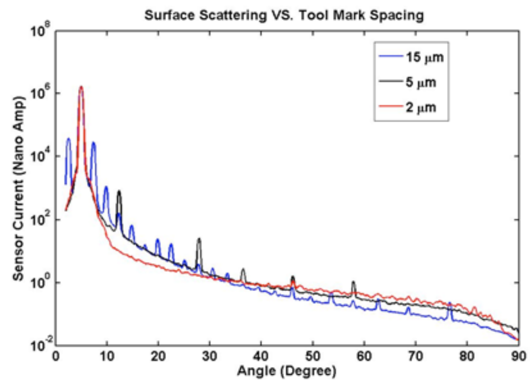

Figure 4(c). Surface scattering of samples

From this research, a basic model for the diamond machining process can be set up (Fig. 5). The specular reflectivity of the diamond machined surface has an optimal tool mark spacing point (point C). Above this point, the specular reflectivity increases as the tool mark spacing is reduced; below this point, the specular reflectivity decreases as the tool mark spacing is reduced. The surface roughness of the diamond machined surface also has an optimal tool mark spacing point (point D). Above this point, surface roughness, R_a, is directly proportional to the tool mark spacing. Below this point, surface roughness is almost a constant value. The shape and the position of the points are also affected by tool condition, tool nose radius, spindle speed, feedrate and other factors.

The research in ultraprecision surface generation offers a fundamental understanding of the diamond turning process, thus providing a foundation for creating functional surfaces with complicated micro- and nanoscale features.

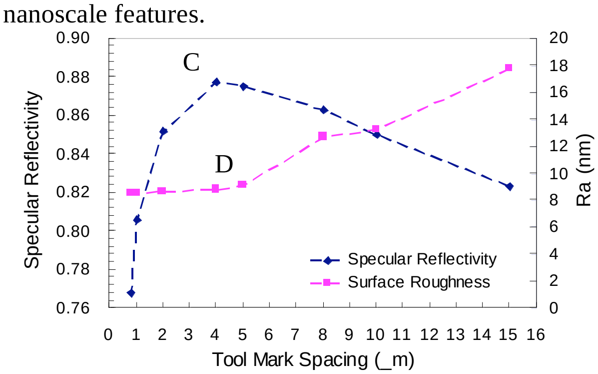

Figure 5. Diamond machining process model

Publications

1. L. Li, S. A. Collins, Jr., and A. Y. Yi, “Optical effect of surface finish by single point diamond machining,” *ASPE Annual Meeting* (2007).

2. L. Li, S. A. Collins, Jr., and A. Y. Yi, “Optical effect of surface finish by single point diamond machining,” Submitted to *International Journal of Machine tool & Manufacture* (2008).

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