Freeform Cubic Phase Plate

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In the March 2004 edition of Convergence, graduate student Wanli Chi and Professor Nicholas George at the University of Rochester's Institute of Optics, presented a fabrication process utilizing deterministic microgrinding (DMG) and magnetorheological finishing (MRF) for a **logarithmic asphere** of BK7 glass to achieve extended depth of field performance in an imaging system.

A parallel project was also on-going to extend the depth of field for a Long-Wave Infrared (LWIR) imaging system. A collaborative effort involving the U.S. Army Night Vision Lab, Moore Nanotechnology Systems and Panasonic Factory Automation demonstrated a successful freeform process for a **cubic phase plate** made of Zinc Sulfide (ZnS), which was the critical component for the imaging system. The resulting surface profile matched the formula to within ±0.20µm. This was deemed essentially perfect, because it corresponded to $\pm 0.02\lambda$ in the 8-12µm region.

The following are abstracts of the design, manufacturing and metrology methods in this project.

Application and Design

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By applying an optical distortion and digital restoration technique to digitally captured imagery, one can realize benefits such as extended depth of field, thermal focus shift invariance, loosened optical design tolerances, and more. The Night Vision and Electronic Directorate (NVESD) began investigating this imaging technique for Long-Wave Infrared (LWIR), low signal applications, since this is predominantly the environment that night vision technology is used. These applications call for fast, wide field of view optics with large depths of field that are covert to threats.

The cubic phase plate design and geometry is shown on the next page in exaggerated forms. The total peak-to-valley on the actual phase plate surface is 100-microns (shown in the formula) whose coefficients are given in millimeters. Note, the base window thickness is arbitrary, but is 3mm (*thi*) for this example. The total plate thickness is *z*, and the x/y origin is at the center of the part. The overall size of the part is 25mm x 25mm.

$$z = 0.025\left(\left(\frac{x}{10}\right)^3 + \left(\frac{y}{10}\right)^3\right) + thi$$

Figure 1: Phase Plate Form

Slow Slide Servo (S^3) Machining Process

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In recent years, a significant amount of work has been accomplished in the area of freeform optical surface generation. Most of this work is driven by market demand for these types of surfaces, which currently includes eyewear, electro-optics, LED optics, defense, automotive, and others. Presently, there are several methods to manufacture such surfaces of which the most common ones are grinding and raster flycutting. Both grinding and raster flycutting rotate the tool and traverse either the tool and/or workpiece in three linear axes to cut the surface. Grinding and fly cutting can produce very accurate surfaces but require long machining cycles and are difficult to set-up. Another method of fabrication is the Fast Tool Servo (FTS), which is widely applied in the contact lens industry. However, most FTS systems have a maximum travel range of less than 1mm and therefore are limited to certain part geometries with small departures.

In this project Moore Nanotechnology Systems demonstrated how they perfected an alternative method of freeform optical surface fabrication, the Slow Slide Servo (S^3). The S^3 method is similar to the FTS in that, the part is mounted on the spindle and as the spindle rotates, the tool oscillates (Figure 3). Unlike the FTS method, the system does not use any additional axes for oscillating the tool; the Z-axis slide generates the oscillations. Another difference is the spindle position control (or C-axis). In a FTS setup, the spindle has an encoder that feeds the position to the FTS unit without putting the spindle in position control. In the S^3 all axes are under fully coordinated position control. The S^3 can oscillate at ranges up to 25mm, is easy to set-up, inexpensive and allows the manufacturing of highly accurate parts.

Since the material for this application is Zinc Sulfide, a negative rake diamond cutting tool was used. The sag of the surface is 100µm Peak to Valley (PV). The form results shown in Figure 5 demonstrate the PV error is 0.26µm and the surface finish shown in Figure 6 has a roughness of 4.6nm Ra.

Figure 2: Moore Nanotech 350UPL

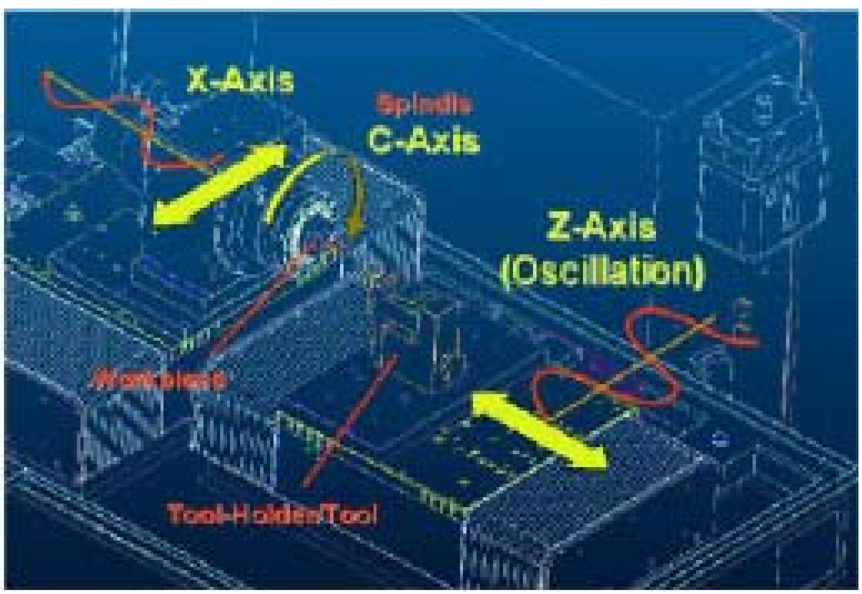

Figure 3: Set up with machining for Slow Slide Servo (S^3)

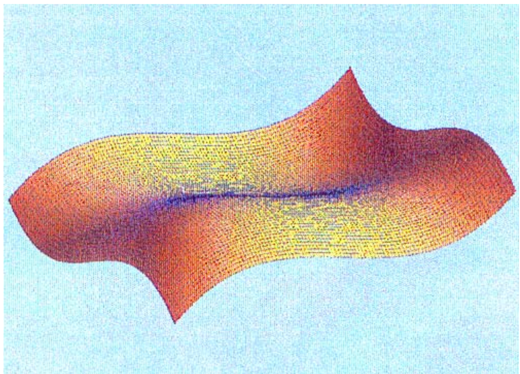

Figure 4. Surface of cubic phase plate.
Material: Zinc Sulfide 27mm X 27mm

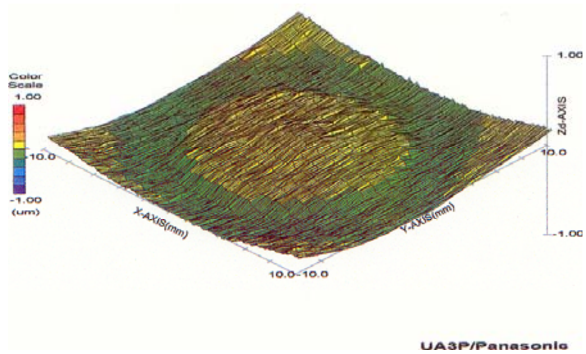

Figure 5. Phase plate form accuracy results
Form results (Panasonic UA3P)
0.263µm PV   0.055µm Rms

Finish results (Zygo NewView)
4.569nm Ra 6.077nm Rms

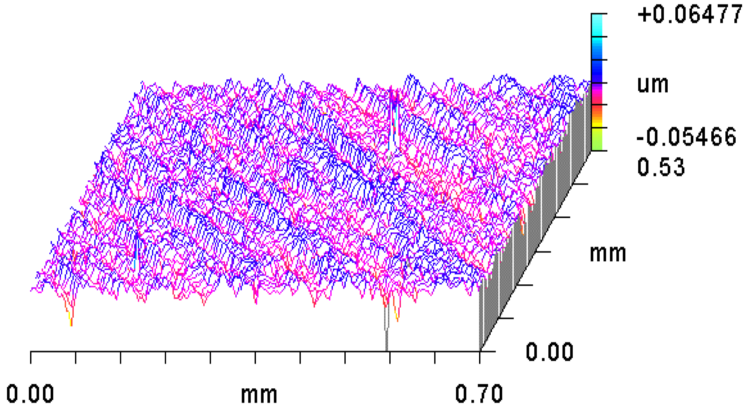

Figure 6. Phase plate surface finish results.

The machining tests performed with the S^3 indicate that it is a very viable method for producing freeform optical surfaces. Surface finish and form accuracy results are comparable to axisymmetric diamond turning results. In addition, this method is inexpensive, does not have sag limitations, is very accurate, reduces cycle times and is easy to set-up.

Metrology : UA3P, Ultrahigh Accurate 3-D Profilometer

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Panasonic's applications laboratory in Elgin, Illinois joined the effort to provide a full aperture (20mm x 20mm) map of the surface.

The Ultrahigh Accurate 3-D Profilometer (UA3P) offers the capability to measure surfaces up to 60^o slope angle, exceeding the capability of COM's interferometers and optical probe-measuring tools. The UA3P combines 3-D measurement capabilities, an interferometer function, atomic force microscopy and roughness measurement in one machine that allows measurements to be taken from objects as small as 2µm to large objects up to 400 mm.

A 2µm diamond stylus was used and a user-defined equation was set up. This set up, using the customer's 3^{rd} order polynomial equation for the object's surface, provided information for the UA3P to compare the measured results to the actual surface topography. The measurement type was a standard X rectangle scan for the UA3P, measuring +/- 10 mm in the X and Y from the center of the object moving at 3 mm/sec. Approximately 7400 data points were collected, but changing the speed and data sampling pitch can collect more data points if needed. After the data collection, the editing features on the UA3P were used to eliminate any noise from the data, such as dust on the surface of the object. When editing was completed, the data was plotted directly from the UA3P in various forms, such as Zd compared to X, Y. (see Figure 5)

Future Efforts: COM is exploring finishing optimization processes for improved surface finishes on polycrystalline IR materials such as ZnS. These efforts will be reported in upcoming editions.