How to Select Optimal Positioning Equipment for Laser Direct-Write Processes

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By: Brett Heintz, Application Engineer

Choosing the optimal automation equipment for a given process requires a thorough understanding of the process parameters and the effects of positioning errors on the results. Recent advances in laser direct-write applications provide an excellent example of selecting the optimal positioning equipment based on process parameters. In general, the laser direct-write process consists of a laser source, focusing optics and motion subsystem to position the substrate under the beam (Figure 1). Traditionally, this process has been used by researchers to write waveguides, fiber Bragg gratings, directional couplers, etc., in fused silica substrates using UV lasers [1]. In industry, the process has been used to successfully manufacture coupling devices for optical alignment in optoelectronic devices and manufacture wearable augmented reality lenses. Current applications of direct waveguide writing have demonstrated the ability to write waveguides, transparent to the human eye, just below and on the surface of Corning Gorilla Glass used for mobile phone displays [2]. Surface plasmon sensors written on the display have the potential to be used for bio-sensing and gas detection. while Mach-Zehnder interferometers can be used for temperature sensing [3].

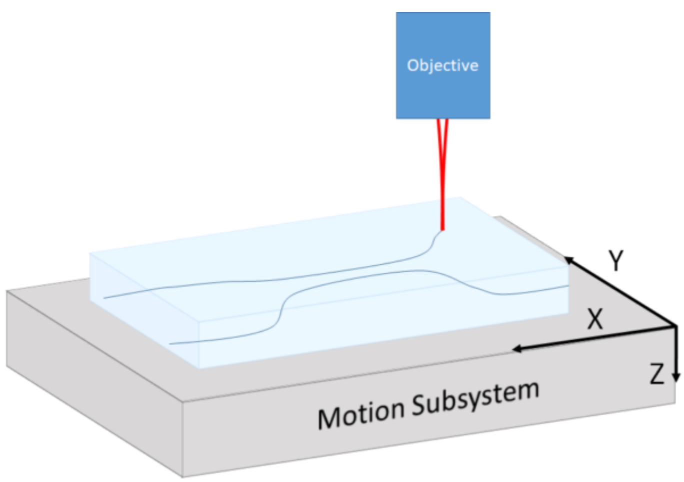

Figure 1. *In a typical laser-direct write setup, XY motion is usually below the substrate. Z (focal motion) may be below the substrate or attached to the objective, depending on process requirements.*

To choose the optimal motion subsystem for inscribing waveguides into mobile phone displays, the process parameters and application goals must be considered. First, the waveguides must be low loss. The wavelength loss of the inscribed waveguides depends directly on the energy density absorbed during the direct write process [3]. Therefore, pulse placement relative to other pulses must be controllable. Synchronizing the pulses to the positioning equipment can be done by relying on the velocity stability of the translation stages under a fixed firing frequency. However, velocity instabilities will cause pulse positioning errors and the user will be forced to program the velocities based on the firing frequency. Rather than rely on the velocity stability of the mechanics, the calibrated encoder position of the mechanics can be used to trigger the laser pulse at the desired location in one, two, or three dimensions with nanosecond latencies from the motion system controls. This allows the user to easily program the motion profile without worrying about pulse placement inconsistencies throughout two-dimensional or three-dimensional (3D) contours (Figure 2).

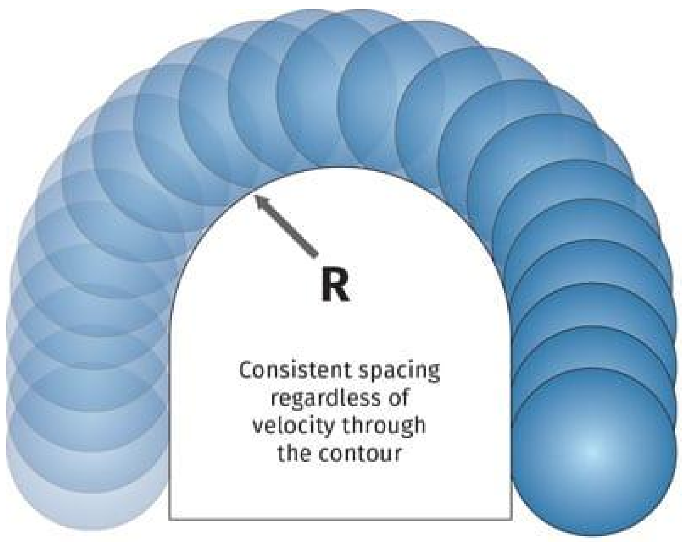

Figure 2. *Synchronizing laser firing with the motion system encoder feedback produces consistent spacing through contours, regardless of commanded velocity.*

Figure 2a. *Pulse synchronization around a corner at 200 mm/s on anodized aluminum plate.*

Production of many waveguide-based sensors within display glass requires the 3D position of the inscribed waveguide to be as close as possible to the designed position. Features such as directional couplers, consisting of multiple waveguides five to nine microns wide, are sensitive to position deviations on the order of 100 nm. Therefore, the positioning system must have sub-micron repeatability in the plane at the surface of the glass display. Traditional three-axis femtosecond laser micromachining positioning systems, such as the small format lab system shown in Figure 3, consist of stacked XY mechanical-bearing stages and independent, vertical-focusing stages. As actuator travels increase to accommodate mobile phone displays, off-axis errors due to rolling bearing elements and stage manufacturing tolerances become more pronounced, resulting in inconsistent positioning between waveguides. For this reason, mechanical-bearing positioners are often replaced with air-bearing positioners that sit on a thin film of air, creating a non-contact bearing surface that eliminates the negative off-axis effects of rolling element bearings. Additionally, the thin film of air generates an averaging effect over the surface of the bearing, mitigating errors due to surface imperfections and manufacturing tolerances, while providing noticeably higher levels of repeatability performance in all directions. This results in repeatable spot placement and, ultimately, higher quality waveguide devices.

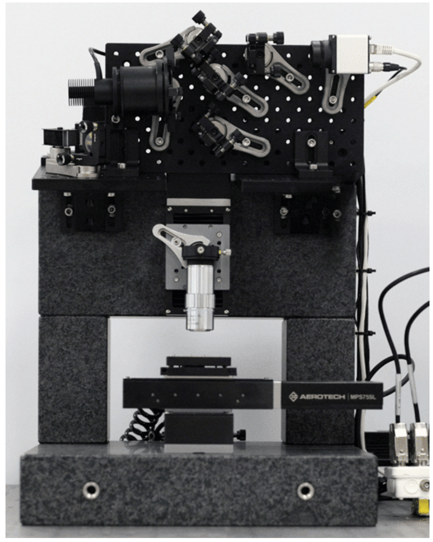

Figure 3. *Small format XYZ femtosecond laser micromachining system. Photo courtesy of Altechna R&D.*

To achieve optimal sub-micron positioning in the XY plane, plane mirrors mounted at the surface of interest and laser interferometers (Figure 5) with high-resolution electronic multipliers, capable of resolving motion down to 0.15 nm, can be used to generate a map of positioning errors. The map can be used to calibrate out the errors over the area where the waveguide sensors will be inscribed, achieving in-plane repeatabilities of +/- 50 nm or better. An H style, planar air-bearing architecture (Figure 4, Figure 5) brings the glass substrate closer to the positioner's encoders, reducing off-axis errors typical in stacked XY systems. This results in the highest accuracy laser spot placement achievable.

Figure 4. *PlanarHD planar air bearing with exceptional geometric performance and +/- 50 nm long-term repeatability.*

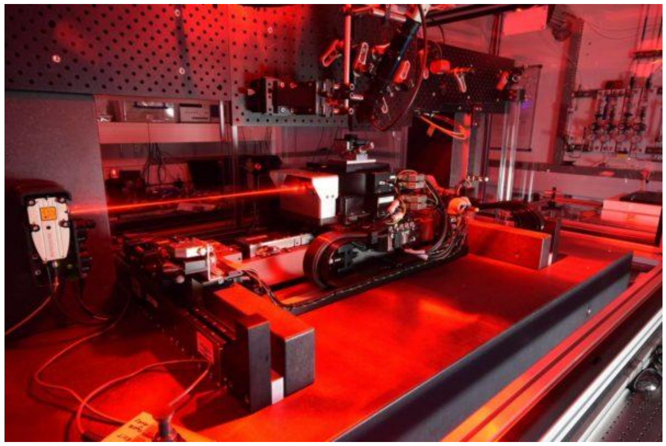

Figure 5. *XY planar air bearing with integral Z/Theta Z stages and 2D laser interferometer feedback for direct ultraviolet writing of waveguides in photonic chips. Photo courtesy of Paul Gow, Ph.D., of the Optoelectronics Research Centre (ORC) at the University of Southampton, England.*

To inscribe multiple sensors into the display surface, the waveguides must be written in 3D space within the glass substrate. Dynamic movement of the focal point along the focal direction during processing generates the desired 3D waveguide structures. Positioning in the focal direction during XY contoured motions must be fast and highly accurate to ensure that unintentional coupling between waveguides does not occur due to inaccurate spot placement. A flexure-based piezo nanopositioner (Figure 5a.) can provide quick, accurate spot placement throughout the 400 micron depth from the display surface (Figure 5b.). Capacitance probe feedback achieves < 10 nm repeatability, allowing waveguide writing directly below the surface of the display for sensing applications.

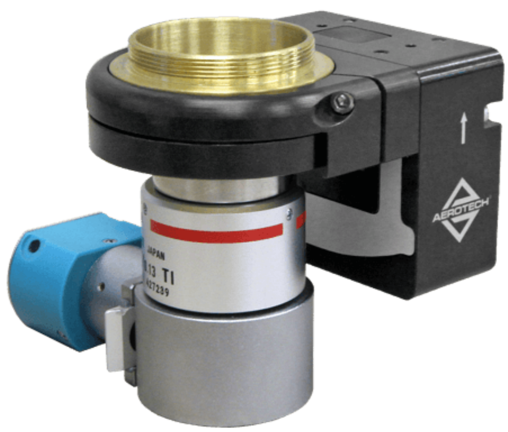

Figure 5a. *QFocus flexure-based piezo allows for fast focal depth adjustment by moving the objective during direct writing.*

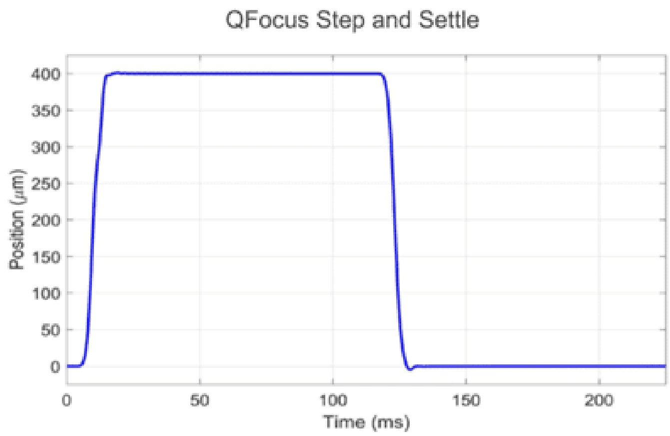

Figure 5b. *QFocus, with no payload, settling within a one percent window in less than 15 ms after a 400 micron move. The same step can be performed with a 150 g payload in less than 30 ms.*

Successfully selecting precision positioning equipment to put a process in motion requires an underlying knowledge of the process parameters and their relationship to the positioning equipment. Advanced manufacturing techniques, such as laser direct write of waveguides in mobile phone displays, rely on optimized precision positioning equipment to achieve new applications with the potential to provide previously unrealizable benefits, such as personal biosensing and chemical detection capabilities integrated into mobile phone displays.

References

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About the Author

Brett Heintz is an applications engineer at Aerotech. He focuses on the technical challenges associated with the design, production, and programming of precision automation systems for optoelectronic packaging and testing. Heintz received his bachelor's degree in engineering physics and his master's degree in electrical and computer engineering from the University of Pittsburgh.