Polytec PI Tech Note

Alignment of Waveguide Devices

Waveguide-class devices are becoming more and more popular as the metro market blossoms. Their complex functionality, parallel multichannel operation and cost-effective planar fabrication open many opportunities for systems designers, and for eventual integration into hybrid electro-optical microcircuits. Today's examples include silicon optical amplifiers (SOAs), arrayed waveguides (AWGs) and integrated optical circuits (IOCs); future uses will include on-board and even in-chip DWDM data buses.

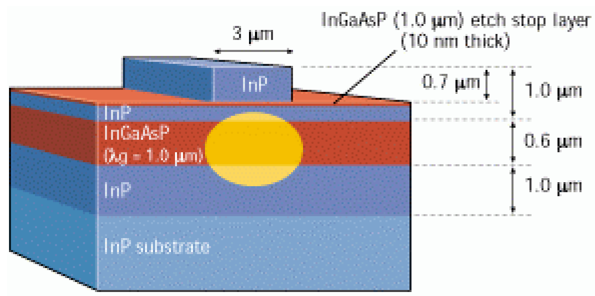

Figure 1. Today's waveguide devices are fabricated using semiconductor wafer processes. This allows sophisticated parallel optical trains to be fabricated cost-effectively. Courtesy WDM Solutions (see Footnote 1.)

Challenges for Automation

Economical packaging depends on the automated alignment of fibers and V-groove arrays to the waveguide channels. Waveguides can be paradoxically simple yet complex to align:

- On the one hand, alignment of a fiber to an individual waveguide channel can closely resemble the straightforward fiber/fiber butt-coupling process most readers are familiar with.
- However, waveguide channels tend to be physically small, with characteristic dimensions as small as 0.2µm, necessitating very high-resolution/high-stability mechanics.
- Waveguide channels are generally rectangular and usually yield a somewhat elliptical, astigmatic wavefront; this can be problematic for some alignment mechanisms.
- Many waveguide devices act as wavelength splitters, with mixed wavelengths at the input resulting in discrete wavelength outputs arrayed by channel. This—combined with fairly large insertion losses—can result in comparatively meager light output, which poses further challenges for some alignment methodologies.
- Angled cleaves must frequently be accommodated.
- Achieving "first light" at the input can be frustrating, as this is often a time-consuming blind process. Fixturing and device non-reproducibility often complicate this fundamental initial task.

Example Application

In this Tech Note we describe a successful implementation of two PI F-206 microrobots for 12-degree-of-freedom alignment of input and output fiber arrays to a multichannel silicon AWG demultiplexer—one of the most challenging devices to align. These increasingly popular devices have multiple input channels carrying photonic bitstreams in mixed wavelengths. The output channels are ordered by wavelength[1] as shown in Figure 2.

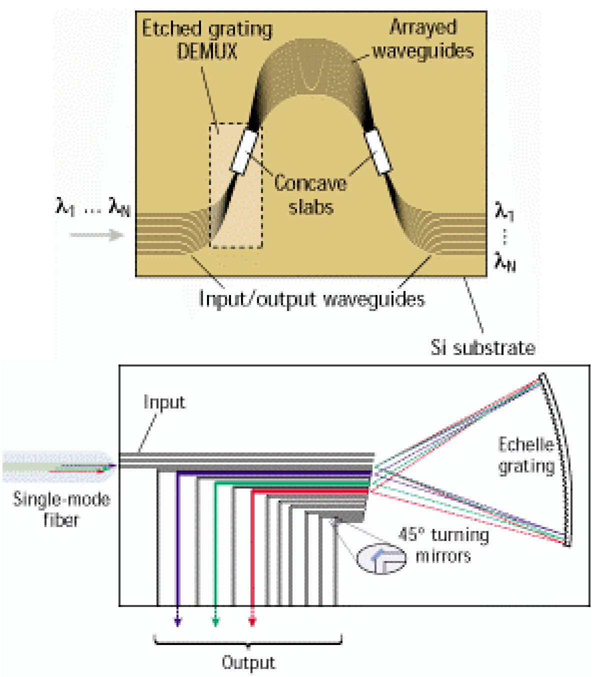

Figure 2. AWG demux and equivalent bulk-optic concept. Courtesy WDM Solutions (see Footnote 1).

Setup

Two F-206s were mounted on an isolation table (see Figure 4). Initially the output of the Si AWG could be imaged by an IR camera to facilitate first-light acquisition. A downward-looking camera is mounted on two PI M-500 stages for viewing the gaps, etc. These stages are controlled by one of the F-206 controllers. The 0^{th} and N^{th} channel fibers from the output array were connected to one F-206's power meter cards. The output of the photoamplifier was connected in parallel to both F-206s' A/D inputs.

A LabVIEW program was constructed to sequence the two microrobots for six-degree-of-freedom alignment of both sides of the AWG. A serpentine seek routine for the two microrobots was programmed to automatically capture first-light at the input, eliminating the need for the back-end IR camera. Fine-alignment commands were then issued to automatically optimize the coupling of the input and output fiber arrays.

The following graphs show the repeatability of the transverse alignment of the single-mode fiber silicon V-groove arrays to the waveguides. Due to the thermally-induced spectral instability of the broadband source (an erbium-doped-fiber laser with only the aggregate integrated power—not the spectrum—stabilized by closed loop) we statistically removed any monotonic trend observed from variation of the source; both the raw and processed data is plotted. The units are Volts and represent the terminal value of each run's optical coupling as viewed by the two F-206s' power meter cards. The repeatability results were then presented several ways: (1) the raw plot, (2) a bar-graph showing the de-trended value of each run, (3) a histogram, (4) an XY plot of the terminal position, (5) mean, standard deviation and variance values.

[1] An excellent article on devices of this type is "Etched InP waveguides speed metro WDM", WDM Solutions, http://wdm.pennnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=94394

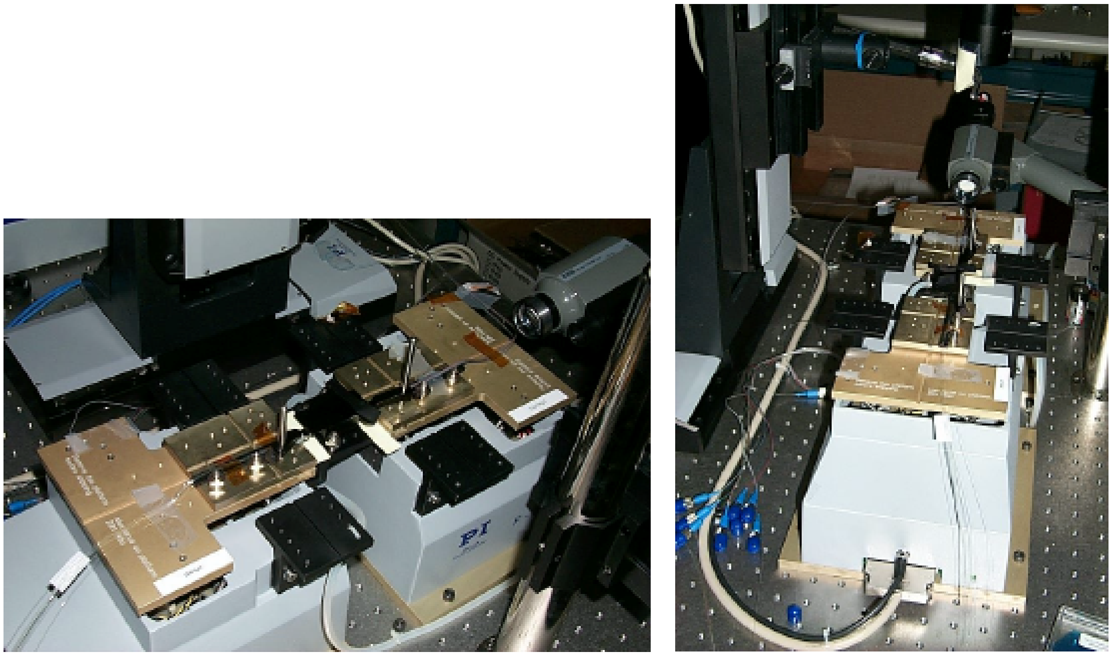

Figure 3. The AWG alignment setup. An IR imager with CCD was used to find first-light. The I/O fiber arrays were each mounted on their own F-206. A PI vacuum chuck for the waveguide was mounted on one F-206's stationary front bracket; the other F-206's bracket was removed; this made for an especially compact assembly. One F-206 controller was used with an XZ assembly of M-500 stages to position a CCD camera above the assembly to facilitate visual alignments.

Results

Of the many alternatives available in the F-206's "toolkit", we selected the FSA algorithm for the very demanding alignment of the quasi-Gaussian couplings to these waveguide. The results (Figure 4-Figure 7) were exceptional:

- Typical transverse alignment time less than 5 seconds from a ~200µm initial offset.
- ~0.1dB transverse alignment repeatability, virtually identical to or even better than a steady-state test with no alignments (see
- Figure 7)
- Terminal positions clustered typically within +/- 0.1µm.

Note: alignment results are highly dependent on device coupling characteristics. Results will vary by application.

The superb performance of the F-206 in the very demanding transverse alignment for these devices allows the fully-integrated system to achieve 0.2dB consistency for the full 12-degree-of-freedom production process:

- A video approach was chosen to achieve the desired 10µm Z separation between the fiber array V-groove assembly and the waveguide input and output faces. The F-206s' capability for placing the centerpoint of its optical axes anywhere in space via a single software command is leveraged here by placing the pivot point on the optical axis of the 0^{th} array channel.
- $?_Z$ alignment (that is, adjustment of the I/O arrays' roll angles to bring all fiber channels into alignment with the waveguide channels) is achieved by the F-206's FAA (fast angle alignment) command.
- $?_Y$ and $?_X$ are readily optimized via the FAM (fast angle scan to maximum) and AAP (automated gradient search) commands.

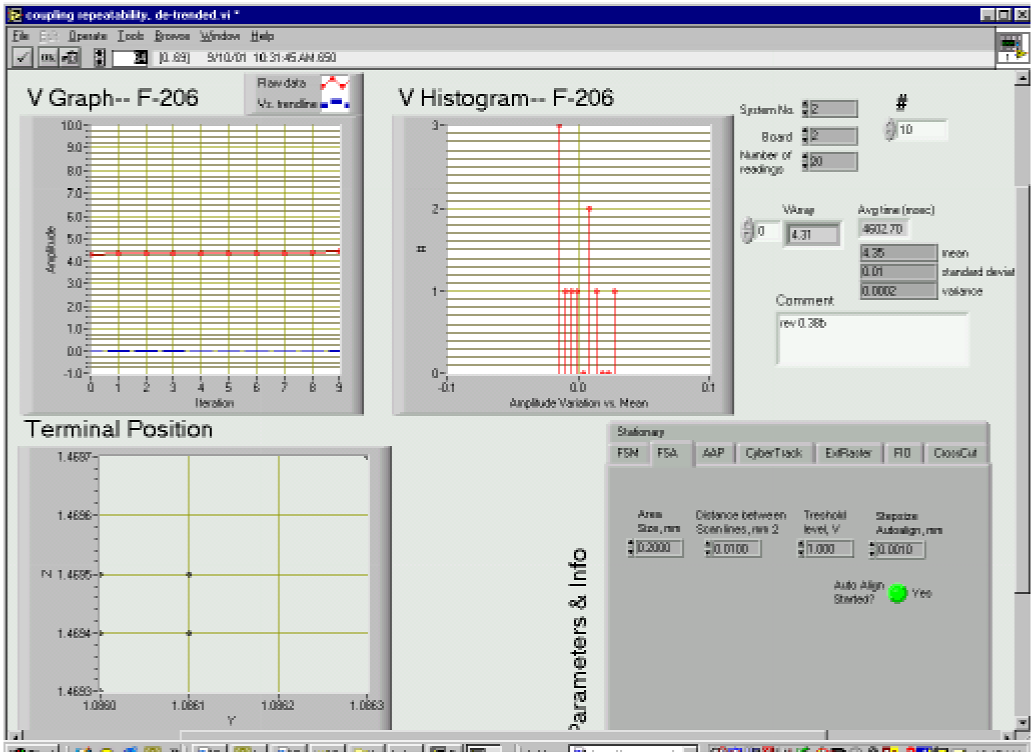

Figure 4. Statistical analysis of ten successive dealignment/realignment operations.

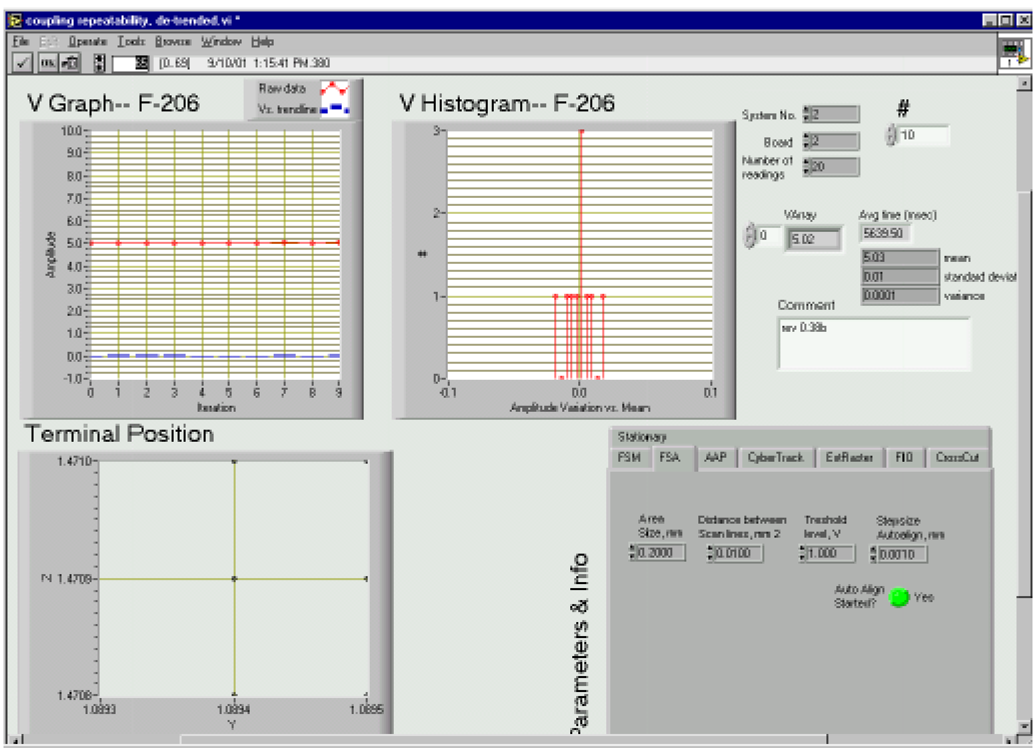

Figure 5. Same test.

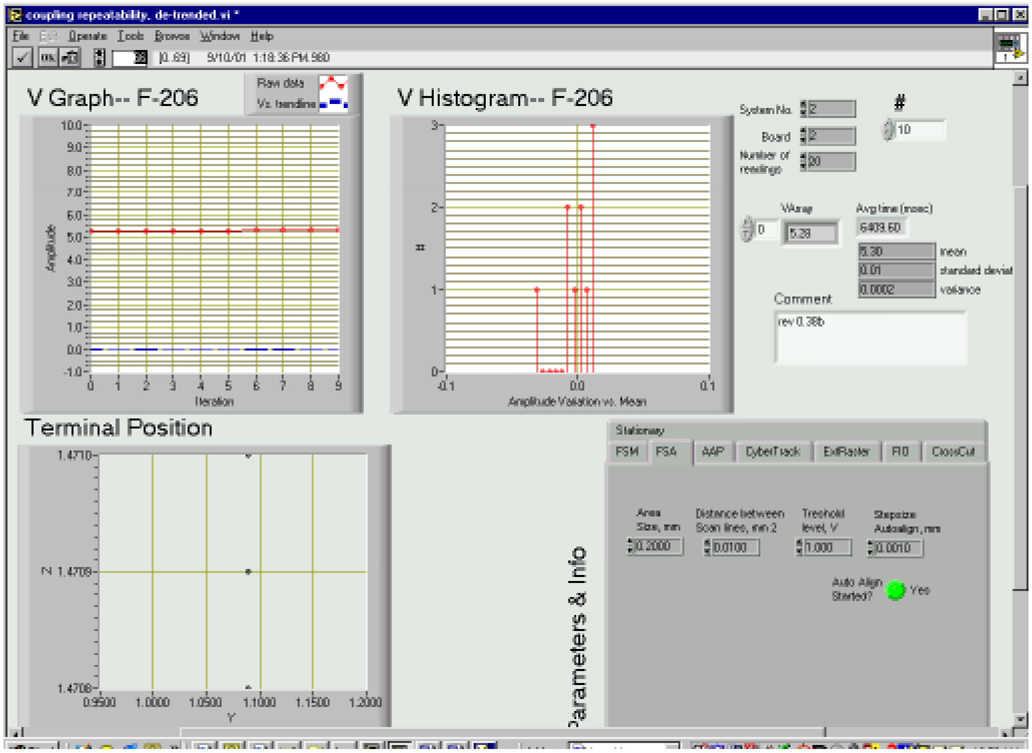

Figure 6. Same test.

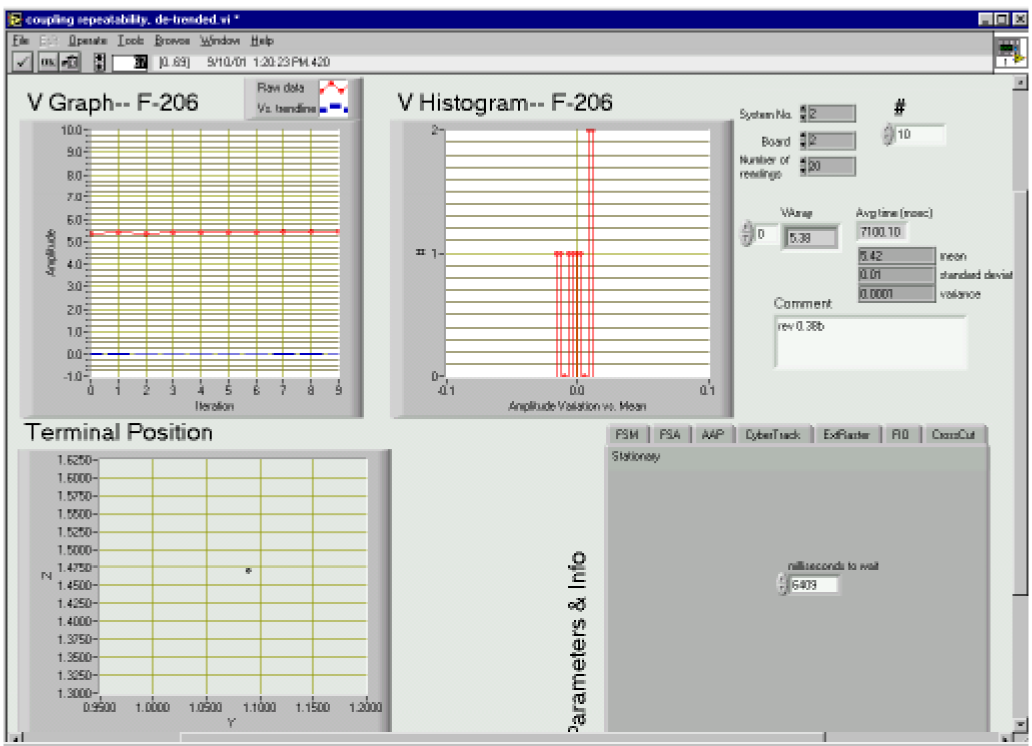

Figure 7. Same test with no realignment at all-- just dwell (approximating the ~4.5 alignment time observed in Figure 4-Figure 6), followed by data collection.

Photonics Production Microrobotics: A Coming of Age

This application represents the convergence of semiconductors and photonics in more ways than one. Most obviously, the silicon AWG is a lithographically-produced pattern imprinted *en masse* on a single wafer, then diced by the dozens. But there is another, less evident parallel: the advent of a novel production robot configuration which addresses unique characteristics of the industry's applications.

The script is reminiscent of thirty years ago, when the first wafer-handling robots were introduced in the semiconductor industry. Early handlers were stacks of linear slides which shuttled wafers from station to station in process tools. A radical departure occurred in the 1980s with the first multi-link wafer-handler robots. These used coordinated counter-rotating axes to fold and un-fold arms, giving the robots long reach with a more compact footprint than was possible with stacked linear configurations. Cleanliness and speed were significant benefits, as the exposed, particle-producing bearings and substantial moving masses of the stacked approach were eliminated. Still, the new configuration was outlandish, and the necessary controls were more complex. It was a few years before it was accepted by tool engineers. Today—with the industry well along in its long-term initiative to improve yield by eliminating manual handling of wafers—these robots are the norm.

A similar evolution is playing out in photonics process automation. The first production-worthy alignment subsystems—such as the earliest digital-gradient-search units, introduced by the author more than a decade ago and still popular—were stacks of off-the-shelf linear stages. Many competitors now offer similar products. In 1997, however, the first hexapod-based photonics microrobot was introduced: PI's F-206. Driven by the photonics industry's own yield improvement initiative—in its case, to eliminate manual alignment processes—this novel configuration addressed emerging needs including:

- Increasing device complexity
- Burgeoning needs for angular as well as transverse alignment
- The need to instantly place the physical rotation center-point at specific optical points (something not possible with mechanical rotary bearings)
- Improved process throughput through elimination of more than 90% of the moving mass of conventional stacked approaches.

After breakthrough deployment as an "enabling technology" in several otherwise-intractable MEMS, DWDM and waveguide applications, the hexapod principle was soon proven to the point that it has become mainstream. Some companies have dozens of these units operating side-by-side, operating 24x7, and the unit is in its fifth year of volume production.

Figure 8. The hexapod parallel-kinematic microrobot follows in the tradition of the multilink wafer-handling robot: once novel, now mainstream. Photo courtesy Equipe/PRI Automation.

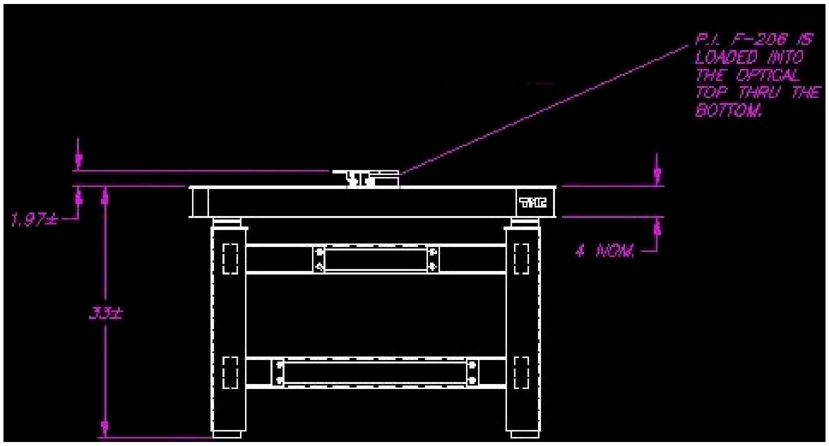

Figure 9. Integrators may be interested in insetting the F-206s into a TMC isolation table. This improves ergonomics, vibrational stability and thermal stability.

Conclusion

The F-206 microrobot has proven to be an ideal platform for this and other waveguide applications due to its:

- High precision
- Six-axis functionality
- Freely software-settable rotational pivot point
- Integrated high-speed metrology
- Compact footprint
- Broad suite of fully-integrated, high-speed automated-alignment routines
- Comprehensive, industrial-class supporting software, including LabVIEW libraries, and COM-compliant 32-bit DLLs.

In this application success story, all of the F-206's attributes were leveraged, resulting in a fast production alignment workstation with alignment repeatable to 0.1dB for the devices' especially demanding transverse alignments and 0.2dB for the full 12-degree-of-freedom application.