Direct UV writing speeds up the exploitation of integrated optics in stellar interferometry

Massimo Olivero, Mikael Svalgaard, Laurent Jocou, and Jean-Philippe Berger

An integrated optical planar beam combiner for near-infrared stellar interferometry has been made by patterning a photosensitive glass with a UV laser.

A stellar interferometer consists of a cluster of telescopes whose signals are coherently combined and processed to retrieve an ultra-high-resolution image\(^1\) (see Figure 1). The angular resolution depends on the separation of the telescopes and not on their individual apertures. This provides stellar interferometers with their main advantage over single large-aperture telescopes: a capacity for much higher resolution measurements. They are now extensively used for imaging compact astronomical sources and are expected to be required in future searches for Earth-like planets.

Beam combination represents one of the most challenging problems in stellar interferometry. It is being addressed by the development of integrated optical components that can perform beam combination from a large number of telescopes thanks to features such as compactness, precise self-alignment, and superior signal-filtering properties. A number of prototype integrated optical beam combiners have already been fabricated by standard photolithography-based techniques in silica glass. However, these fabrication methods are fairly slow and expensive, especially where stringent performance requirements necessitate extensive design optimization. Hence the need for a faster and cheaper prototyping method. A European collaboration between engineers and astronomers has recently addressed this challenge with their design of an integrated optical beam combiner fabricated with a UV laser beam.\(^2\)

Direct UV writing is a fabrication technique where high-performance waveguides are written directly into a planar glass sample with a focused UV laser\(^2\) (see Figure 2). The optical circuit is defined by the UV beam scan pattern, and hence direct writing does not require a photolithographic mask. Furthermore, any optical waveguiding structure can easily be generated by programming the scan sequence. The technology was originally developed for low-cost telecom components such as optical power splitters\(^3\) and broadband couplers.\(^4\)

For demonstration purposes, we built a dual beam combiner with two interferometric and two photometric outputs (see Figure 3). Beam interference was achieved with an asymmetrical 3dB directional coupler\(^4\) that allows broadband performance, while the photometric outputs were generated using 3dB Y-branch power splitters.\(^3\)

The characteristics of these subcomponents were controlled by tailoring the applied scan velocity during UV writing. The total device length was 15mm, or \(\sim 1/3\) of that reported in a previous demonstration based on ion-exchange technology. Writing took less than 5min. The component was also designed for pigtailin...
Figure 2. (a) A diagram illustrates the principle of operation of UV writing. (b) Direct UV writing is seen in action.

with standard optical fiber array connectors. The total time required for design, layout definition, and fabrication of the dual beam combiner was \(\sim 1\) week, thus demonstrating the fast prototyping capability of UV writing.

Loss measurements (see Figure 4) showed a constant total loss of \(\sim 0.7\) dB throughout the entire sampled spectral range from 1.3 to 1.75 \(\mu\)m. This value is roughly five times lower than that achieved previously, mainly due to the use of a coupler for beam combination rather than a splitter and better mode matching to optical fibers. The splitting ratio was also flat and well centered on the required 3dB. The coupling ratio exhibited a \(\pm 0.5\) dB flatness over a 0.25 \(\mu\)m range. In slightly different coupler designs, we were able to achieve a \(\pm 0.5\) dB bandwidth up to 0.45 \(\mu\)m.\(^4\) This bandwidth matches the best results obtained with more complex designs using other fabrication techniques. This is because direct UV writing has the unique capability of efficiently optimizing the propagation properties of the waveguides by local control of the refractive index.

Interferometric measurements carried out on a dual telescope testbed showed that the component exhibits a fringe visibility up to 99\%, exceeding the 92\% value obtained with a previous design using integrated optics technology. The differential chromatic dispersion between the interferometric paths, which hampers the response of the interferometer, is also quite low compared with other demonstrations. This is due to high fabrication repeatability, resulting in negligible differences between the propagation constants of the interferometric arms. From loss measurements and interferometric characterization, it is expected that the directly UV-written dual beam combiner will be functional through a wide range of near-infrared astronomical bands.

Continued on next page
Direct UV writing is an effective tool for making customizable, high-performance integrated optical devices for stellar interferometry. The simple dual beam combiner described above is also readily scalable to accommodate more input beams. Further developments will include the design of more complex device functionalities as well as research on new photosensitive materials for extending the operating range to the mid-infrared.

Author Information

Massimo Olivero
PhotonLab
Politecnico di Torino
Torino, Italy

Mikael Svalgaard
Research Center COM
Technical University of Denmark
Lyngby, Denmark

Laurent Jocou and Jean-Philippe Berger
Laboratoire d’astrophysique
Observatoire de Grenoble
Grenoble, France

References