

Femtosecond Laser Irradiation and Chemical Etching (FLICE); Waveguide Writing

Microfabrication technologies have miniaturised many fields, from microelectronics to photonics, paving the way for a wide range of new applications. In particular, the capability of realising microfluidic channels has revolutionised the field of optofluidics.

Microfluidic channels and patterns are typically fabricated by lithographic and chemical-etching techniques, but these approaches are primarily limited to the fabrication of two-dimensional patterns on the surface. Indeed, in order to create a true 3-D structure several layers of glass substrates need to be patterned, etched and fused together.

Femtosecond Laser Irradiation and Chemical Etching (FLICE) allows 3-D micromachining, thus permitting the direct fabrication of buried microchannels with various aspect ratios and patterns.

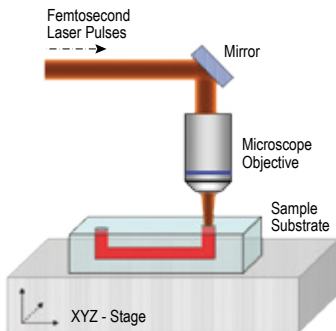
Being a maskless technology, it enables rapid low-cost prototyping of new devices. Moreover, since the same femtosecond laser can be used to produce low loss optical waveguides in a 3-D geometry, these femtosecond laser based technologies could become a single solution for fabrication of microfluidic channels and their integration with optical circuits.

THE FLICE FABRICATION PROCEDURE

STEP 1.

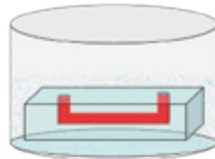
Femtosecond laser irradiation with intensities below the laser ablation threshold.

--> Design of microchannels is imprinted into the substrate volume (typ. fused silica)



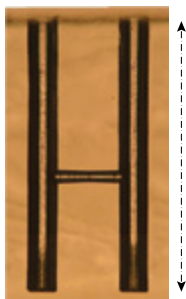
STEP 2.

Etching of the femtosecond laser modified region using HF acid (highly selective).

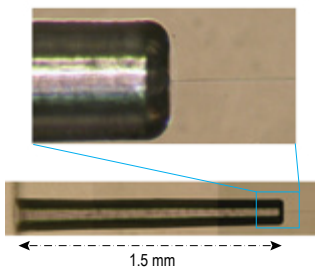


Etching Bath
20% HF

RESULT

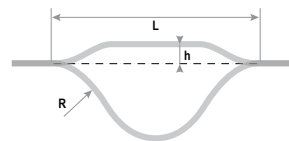


RESULT



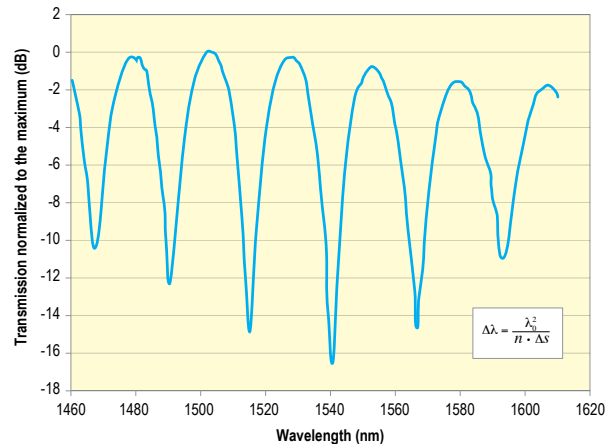
APPLICATION EXAMPLE: Mach-Zehnder Interferometer

Femtosecond laser writing technique enables fabrication of unbalanced Mach-Zehnder interferometers in fused silica substrate. The SHG output at 515 nm of 350 fs laser pulses has been used at 1 MHz repetition rate and focused with a 50x 0.6NA objective. Devices were written 200 μm below sample surface, with a translation speed of 100 μm/s and pulse energy (at 515 nm) of 90 nJ.



$$P_{out} = \frac{P_0}{2} \left[1 + \cos\left(\frac{2\pi}{\lambda} n \Delta L\right) \right]$$

Schematic of the unbalanced Mach-Zehnder interferometers fabricated. The formula of the transmitted power as a function of the input wavelength λ , in the ideal case is reported below (n is the refractive index and ΔL is the difference in the length of the two arms). The measured spectral response of an interferometer with $h = 50 \mu\text{m}$, $R = 30 \text{ mm}$ and $L = 18 \text{ mm}$ is shown in the graph. A fringe visibility of more than 8 dB is observed. The measured fringe periodicity of 25.8 nm is in good accordance with the result of the formula in the inset (24.6 nm), which gives the approximate periodicity of the wavelength fringes in a region around λ_0 (here assumed to be 1550 nm).

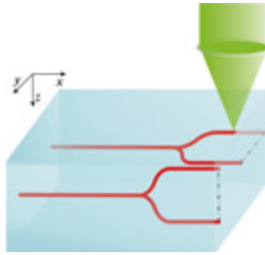


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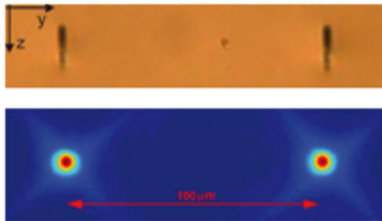
APPLICATION EXAMPLE: 1x2 Vertical and Horizontal Power Splitters

In order to realize complex 3-D photonic devices, it is necessary first to fabricate the basic 3-D optical elements with good guiding properties. A core element is represented by a 1x2 power splitter with certain characteristics: directly buried in the substrate, different possible orientations in the volume, small size.

Scheme of the 1x2 power splitters with two different orientations.

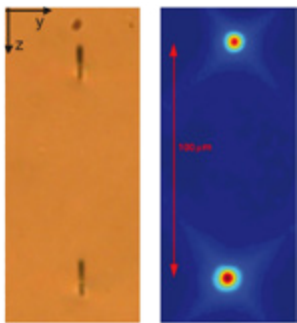


RESULT: HORIZONTAL SPLITTER



Intensity mode profiles at 1550 nm of the horizontal and vertical splitters
Distance between the two waveguides: 100 µm
Splitter size: <2.5 mm
Total insertion losses lower than 5 dB @ 1550 nm

RESULT: VERTICAL SPLITTER



MATERIAL

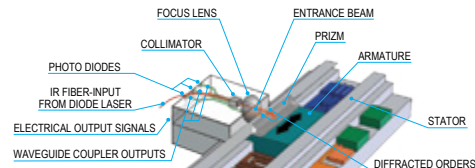
Fused Silica

LASER PARAMETERS

Wavelength 515 nm
Pulse length 350 fs
Repetition rate 1 MHz
Pulse energy 90 nJ
Scan speed 10 µm/s
50x focusing objective with 0.6NA

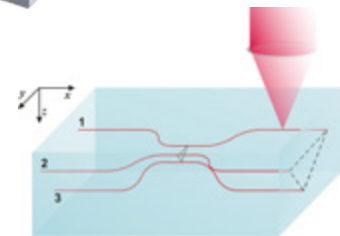
APPLICATION EXAMPLE: 3-D Directional Coupler for a Micromotor Speed Sensor

An important issue in the application of micrometric motors is the capability to fabricate integrated position sensors of high precision (<100 nm) and small size (<10 mm). The project of such a micromotor has been developed by the Laser Zentrum in Hannover; the core device of the speed sensor is represented by a 3-D directional coupler fabricated at Politecnico di Milano. This speed sensor is based on interferometric effects and it needs three coupled waveguides to detect both the motion and direction of the motor speed.

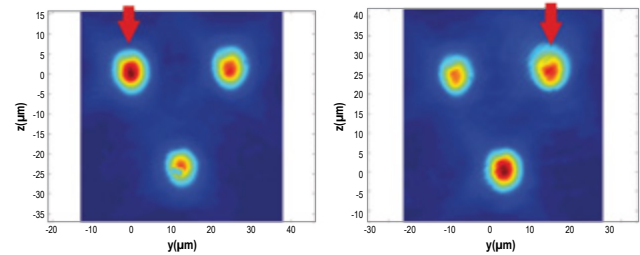


Scheme of the micromotor with the integrated interferometric speed sensor.

Scheme of the 3-D direction coupler composed of three femtosecond laser written waveguides.



RESULT



Intensity mode profiles at the waveguide outputs of the 3-D directional coupler.

MATERIAL

Borosilicate Glass

LASER PARAMETERS

Wavelength 1030 nm
Pulse length 350 fs
Repetition rate 1 MHz
Pulse energy 300 nJ
Scan speed 10 mm/s
20x focusing objective with 0.4NA

ACKNOWLEDGEMENTS: This work was performed at the Dipartimento di Fisica, Politecnico di Milano, Piazza L. da Vinci 32 20133 Milano, Italy | Roberto Osellame, Giulio Cerullo | Tel. +39-02-23996164 Fax +39-02-23996126 | E-mail: roberto.osellame@polimi.it, giulio.cerullo@polimi.it | <http://www.cusbo.polimi.it>. This work was supported by the European Commission (STREP EU: FP6 IST-2005-034562, "HIBISCUS")



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