

## CHROMATIC CONFOCAL PROFILOMETER

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### RESUMEN

Se presenta un perfilómetro óptico no contacto basado en el principio de multiplexado focal por codificación de longitudes de onda mediante un lente de fase de fresnel. El sistema usa una novedosa fuente de iluminación policromática generada mediante un efecto no lineal en fibra óptica monomodo estándar. El análisis espectral de la luz detectada produce la codificación de la altura, identificando la más intensa componente espectral que proviene de la muestra. La sensibilidad de altura del perfilómetro está relacionada con el ancho de la respuesta espectral, la cual depende del poder de resolución del elemento dispersivo y del sistema de detección.

### ABSTRACT

A non-contacting optical profilometer, based on the principle of focus multiplexing by wavelength encoding due to a phase Fresnel lens, is presented. The system uses a novel polychromatic illumination source generated by a non-linear effect in a standard single mode optical fiber. The spectral analysis of the detected light gives the height decoding, by identifying the most intense spectral component coming from the sample. The height sensitivity of the profilometer is related to the width of the spectral response, which depends on the resolving power of the dispersive element and the detection system.

### INTRODUCTION

The confocal scanning technique is attractive for various microscopic imaging applications because of its capabilities of superior resolution, rejection of scattered light and depth discrimination. In this technical, the height of each point of the surface is measured by the  $z$ -location of the sample along the optical axis that leads to the maximum detected intensity. Our system eliminate the  $z$ -mechanical displacement by means of an axial wavelength encoding using the strong chromatic dispersion of a Fresnel lens. Our experiment uses a polychromatic illuminated source which offers a wide and stable spectrum generated by means of standard single mode fiber using a nanosecond microchip laser.

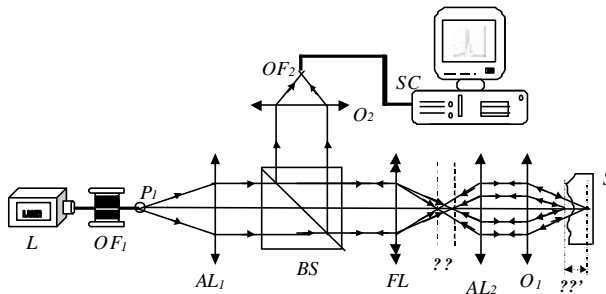
**CHROMATIC DISPERSION AND CONFOCAL MICROSCOPY**

The chromatic aberration is the deformation of an image due to dispersion phenomenon of non monochromatic light through the lenses of an optical system[1]. In this experiment we are interested only in the longitudinal aberration. In this case, different spectral components are focused on the optical axis (axis  $z$ ) at different positions. The dispersion element used is a Fresnel diffractive lens[2,3]. In order to realize a longitudinal chromatic codification of  $z$ , every focal position  $f(I)$  can be converted to  $z$  relative positions by  $z_I = f(I) - f(I_2)$ , where  $f(I_2)$  is a reference focal position. On the other hand, in a classical confocal systems the 3D point spread function (3PSF)  $I(x,y,z)$  is an important parameter for the characterization of confocal imaging systems[4]. Placing a mirror perpendicularly to the optical axes at  $z_o$  position, the spectral components of reflected signal  $I(I)$  (spectral response of the system) can be calculated by the superposition:

$$I(I) = \int I(x,y,z_o - z_I) dx dy \tag{1}$$

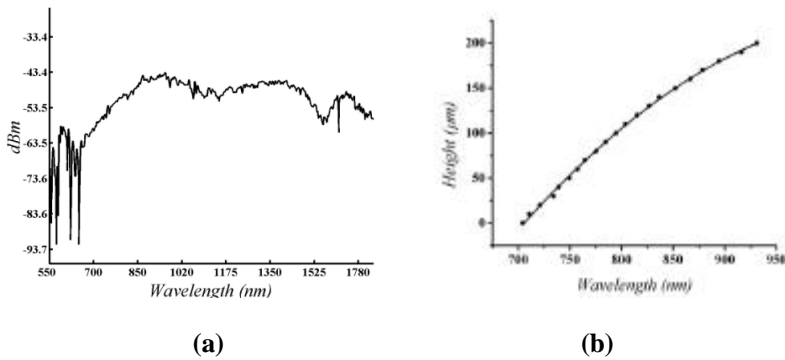
**EXPERIMENT AND RESULTS**

The Fig. 1 shows our experimental setup based on the longitudinal chromatic aberration in confocal microscopy. The three conjugated points are the polychromatic illumination source  $P_I$ , the focal point  $P(I)$  for a determined wavelength  $I$  on the interval  $\Delta I'$  and the detection system input  $OF_2$ . The main characteristic in our system is the illumination source, where a supercontinuum spectrum was generated focusing a pulsed laser  $L$  of 532 nm (average power: 10 mW, pulse width: 0.6 ns, repetition rate: 8-13 KHz), upon a standard single mode fiber  $OF_1$  (length: 600 m, NA: 0.15, core diameter: 8  $\mu$ m). The Fig. 2-a. shows the spectrum generated[5,6].



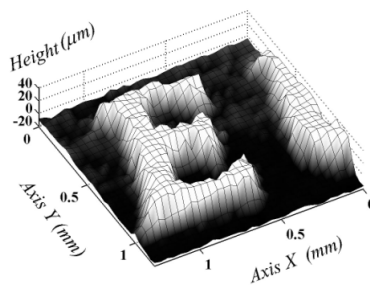
**Fig. 1** Confocal microscopy by longitudinal chromatic aberration

The achromatic lens  $AL_1$  (focal: 20 mm) produces a collimated polychromatic illumination. The longitudinal chromatic aberration phenomenon is produced by a diffractive Fresnel  $FL$  (diameter: 8 mm, focal: 25 mm for a wavelength of 633 nm). So, a wavelength segment  $DI$  is formed. The achromatic lenses  $AL_2$  and  $O_1$  have been introduced to change  $DI$  according to desired measurement range. A value  $DI$  of 3.87 mm was obtained for the spectral components of 700 nm and 938 nm. A value  $DI'$  of 0.2 mm was adjusted using a achromatic lens  $AL_2$  (focal: 20 mm) of and a microscope objective  $O_1$  of 50 $\times$ . The luminous signal reflected by the object surface  $S$  is deflected toward the detection system by means of a beam splitter  $BS$ . A microscope objective  $O_2$  of 10 $\times$  (NA: 0.4) injects the signal into the fibred digital spectrometer  $SC$  (band width: 341.73 - 1001.58 nm, resolution: 0.34 nm).



**Fig. 2. a)** Supercontinuum generated in a single mode optical fiber using a pulsed laser radiation. **b)** Calibration Curve.

Using a mirror, the spectral response  $I(I)$  for different  $z$  positions inside the wavelengths segment image  $DI'$  was obtained. By means of a quadratic approximation between the most intense spectral component of  $I(I)$  and  $z$  position of the mirror a calibration curve was obtained. Fig. 2-b.



**Figure 3.** Topography of the smaller letter E obtained from a coin of 0.10€

Finally, the surface profile of the smaller letter E belonging to a coin of 0.10 € was rebuilt using two translation stages (On the position S, Fig. 1) of 10- $\mu\text{m}$  of transverse resolution in the directions  $x$ - $y$ . Every position  $x$ - $y$  of the object reflects the most intense spectral component of  $I(I)$  and the  $z$  position by calibration curve was obtained. The Fig. 3 shows the measured profiles. The axial resolution is related with the measure of the Full Width Half Maximal Value FWHM. Because the spectral response depends of wavelength, the FWHM has different values. From 700 nm to 938 nm the experimental values for the FWHM changes from 18  $\mu\text{m}$  to 6.48  $\mu\text{m}$  respectively.

## CONCLUSIONS

A system of chromatic confocal microscopy by means of a supercontinuum light generated through a standard single mode fiber has been presented. The system has the following advantages: First, the illumination source has a wide spectral band that allows us a great axial work dynamics. The reduced numerical aperture of the optical fiber in the illumination source and detection systems eliminates the pinholes used in classical confocal microscopy[7]. Second, the wavelength-height codification eliminates the scanning axial device used in classical confocal microscopy. Additionally, the values FWHM can be reduced, choosing microscope objectives with higher numerical aperture or choosing the spectral band of the illumination source inside the far infrared.

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