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Interference of speckle patterns projected by multimode fibers

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ABSTRACT

In This paper, the interference speckle patterns generated by multimode optical fibers are described. In our experience two types of interference are present, random interference between modes propagated in the fiber that give rise to speckle pattern, and not random speckle interference patterns using a Michelson interferometer generating a pattern of conventional interference. Multimode fibers using different materials and core radii have been obtained interference patterns quality characteristic reducing the effects of modal noise in fiber speckle patterns. Experimental results and their potential applications are presented.
Keywords: interference speckle, speckle fiber, speckle pattern, multimode optical.

1. INTRODUCTION

The Recently many research papers have focused their interest in multimode optical fibers in order to use them in future communications systems leveraging spatial degrees of freedom of the multimode fiber, this is the space-division multiplexing [1]. Indeed, the largest diameter core multimode fibers with respect to the single mode fiber allows the selective injection of spatially separated modes. On the other hand, it is well known that when a coherent beam propagates in a well-structured fibers such granular light pattern (speckle pattern) is observed at the output of the fiber [2]. Rather than in optical communications, the presence of speckle is a problem due to modal dispersion, this drawback is exploited in metrology or in sensors to measure physical parameters using the correlation between changes in the speckle pattern with the disturbance in a portion of the fiber [3-4]. The fiber speckle phenomenon is due to random interference between modes propagating with different phases and many papers have been published on this subject. In the interference phenomenon of two or more waves, the polarization of the beams play an important role. Thus, each individual speckle polarization state has a randomly distributed within the pattern remains and propagates beyond the outlet end of the fiber. This phenomenon is not observed when the light is not consistent, such as electro-luminescent diodes (LED).

Motivated by previous experimental work on the degree of polarization in multimode fibers and their relationship with the speckle pattern, we decided to perform the superposition of these patterns, because if we manage to match two speckles can have a phase difference of 2π, so you can get a predictable pattern of interference and not random. Generally, interference between speckle patterns has been performed with systems in volume where the speckle pattern is obtained by reflection of the coherent beam on rough surfaces or through scattering elements [5 - 6], but not with speckle patterns generated fiber multimode. This paper intends to make the speckle interference patterns generated by using a Michelson optical fiber assembly. Various types of multimode fiber have been studied at different wavelengths, showing experimentally that the polarization state in multimode fibers remains some distance outside the fiber. Further demonstrates the effect of the coherence length of the source.

2. THEORY

The amount of speckle in a multimode optical fiber is approximately equal to the number of modes M supported by the fiber [1]. For a step index fiber, is given by $M= V^2/2$, where V is the normalized frequency given by $V=(2\pi a/\lambda_0)(NA)$, where a is the core radius of the fiber, λ_0 is wavelength in vacuum from coherent source and the numerical aperture NA given by $NA= (n^2_{co}-n^2_{cl})^{1/2}$, with n_{co} and n_{cl} the refractive indices of core and cover, respectively. This approximation is valid for strongly multimodal fibers and high numerical aperture. In the case of weak guided, the numerical aperture is approximated by $NA\approx n_{co}\,(2\Delta)^{1/2}$, where $\Delta= (n_{co}-n_{cl})/n_{co}$, so the number of modes is given by: $M=(2\pi a\, n_{co}/\lambda_0)(2\Delta)^{1/2}$. For a

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fiber gradient index is the number of modes $M=V^2/4$. Table 1 shows the parameters of different multimode fibers is summarized. When the output beam of a multimode fiber is projected onto a screen speckle pattern is observed. The height, s, of speckles space depend on the distance (L) from the outlet end of the fiber and the sensing surface or screen, the diameter of the core ($2a$) and λ_0 determined in parallel and perpendicular to the axis propagation: $s_\perp = \lambda_0 L/2a$ and, $s_{//} = 4\lambda_0(L/2a)^2$ [7].

The optical fiber speckle phenomenon is attributed to random interference between modes propagating with different phases. In the output section of the fiber, the light at each point is the sum of contributions of several modes, which far field is observed as an interference pattern granules compounds bright light on dark background. Bright light granules vary slowly in time due to factors environments such as temperature variations that change in refractive index of the core and fiber diameter. Globally, the total intensity of the speckle pattern is constant. A study of interference between modes that give rise to speckle ela has been made in reference [3]. If each individual speckle has an intensity Ii given by the total intensity is approximately constant, that is,

$$I_t = \sum_{i=1}^{M} I_i = \text{cte} \tag{1}$$

where M is the total amount of speckle. So far, the properties of the speckle pattern are determined statistically. If this pattern is divided into speckle intensity and then superimposed with the aid of an interferometer (for example, Michelson), we would observe an interference pattern is predictable. In this case, the equation for two-beam interference is written:

$$I = I_1 + I_2 + \sqrt{(I_1 I_2}\left|\gamma\right|\cos\phi \tag{2}$$

where I_1 and I_2 are the intensities of the two waves, $|\gamma|$ module is the normalized cross correlation of the two amplitudes, and ϕ phase difference between the two waves. The appearance of the new pattern is formed by interference fringes, where the bright fringes correspond to overlapping speckle phase, while dark stripes corresponds to the overlapping speckle out of phase. The properties of this interference pattern are known and can be determined analytically.

Table 1. Types of multimode optical fibers

Type of fiber	Diameter core/cladding (μm)	Refractive index (n_{co})	Numerical Aperture	Number modes*
Silica glass multimode fiber (graded index)	50/125	1,457	0.2	35
Silica glass multimode fiber (graded index)	62.5/125	1.457	0.2	44
Perfluorinated POF (graded-index)	62/500	1.358	0.2	665
PMMA (step-index)	240/250	1.49	0.5	184,884
PMMA (step-index)	980/1000	1.49	0.5	3'082,691

*calculated with λ=0.6328 μm.

3. EXPERIMENTS AND RESULTS

Figure 1 shows the experimental setup for interference between speckles patterns generated fiber. The experimental setup consists of a coherent light source (He-Ne laser to λ= 0.6328 μm), linearly polarized and coupled multimode optical fiber using a microscope objective for fibers of core 50 μm and core 62.5 μm, and coupling directly the beam in fibers 240μm and core 980 μm, respectively. The light coupled into the fiber becomes propagation modes (LP modes) and random interference between modes give rise to speckle pattern. At the fiber output, the beam is collimated with a lens and projected onto the input of a Michelson interferometer. The beam splitter divides the pattern into two patterns of equal intensity and are superimposed after being reflected by mirrors M_1 and M_2, respectively. Finally, by careful adjustment of the phases, an interference pattern, similar to those obtained in conventional assemblies, is obtained. The interference pattern is observed on a screen and recorded by CCD camera. With this assembly are realized interference speckle patterns obtained in a variety of multimode fibers with core diameters of 50 μm, 62.5 μm, 240 μm and 980 μm, and gradient-index profiles and step-index. The characteristics of the fibers are shown in Table 1 were used fibers 3 and 20 meters long.

The interference fringes, in our case, corresponding to bright and dark rings concentrically distributed, relatively easily obtained when the amount of modes correspond to tens or several hundreds of modes, which are instances of the fibers with core diameters of 50 μm and 62.5 μm, respectively. Increasing the core diameter increases the amount of fiber modes but decrease the size of the speckles thus adjusting phases presents additional difficulty, but also interference patterns are obtained. All the photos captured speckle patterns and interference Hans been made keeping the same position of the fiber at the input of the interferometer and the CCD camera-screen distance.

Figure 2 shows photos of speckle patterns and interference from both obtained with a fiber multimode 240 μm core diameter step index based polymethil-methacrylate (PMMA). The fiber used is 3 meters long. Figs. 2 (a) and 2 (b) are the photos of the two speckle patterns reflected by mirrors M_1 and M_2 taken separately. Fig. 2 (c) shows the interference pattern between the two speckle patterns obtained when the phase delays is 2π. It can be seen well the bright fringes light containing granules of light as mentioned in section 2. The light in these granules retain their activity and are sensitive to perturbations on the fiber, whereas the interference fringes of the interferometer Michelson remain undisturbed and obey the conditions of the interferometer. Fig. 2(d) shows the interference pattern after subjecting the fiber to a radial vibration frequency of 50 Hz using a speaker. This shows that the speckle interference pattern within retain their sensitivity, and speckle removal by vibration techniques [8] can get a clean stripe pattern and open new possibilities for use in optical metrology.

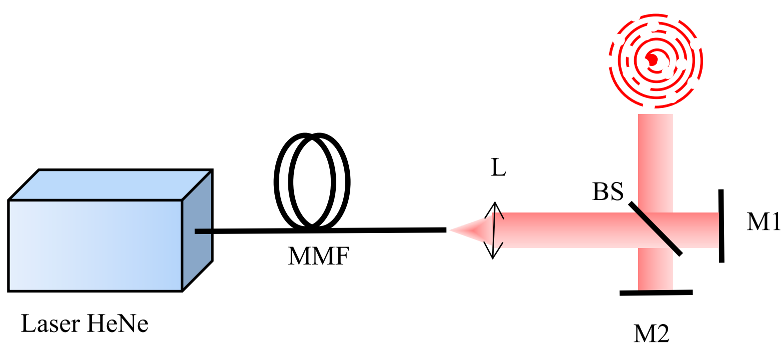
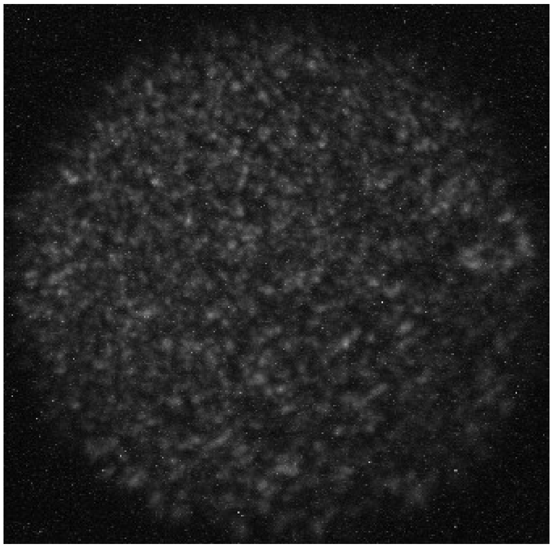
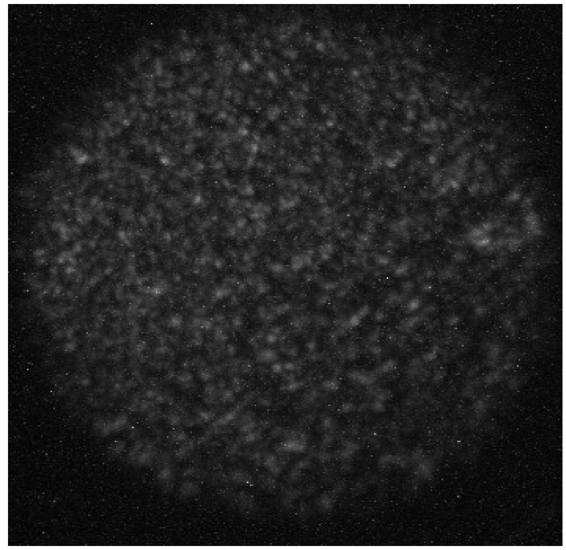


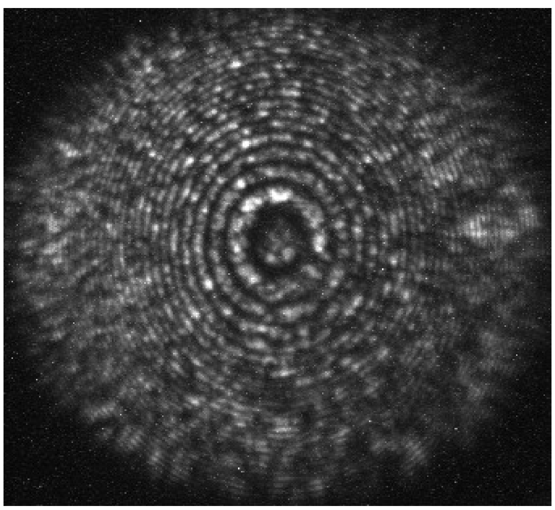
Figure 1. Experimental setup for generation and interference speckle pattern.



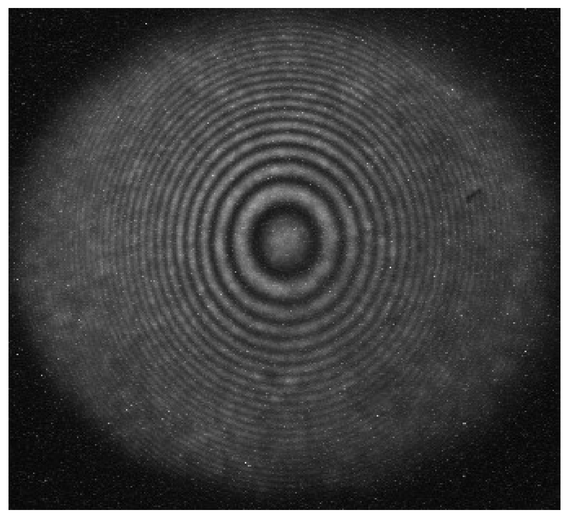
(a)



(b)



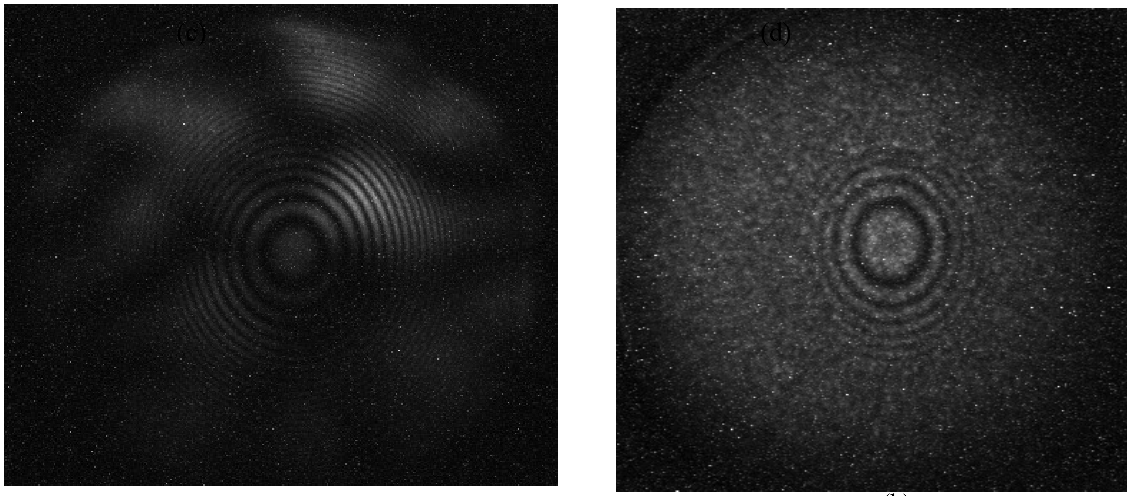
(c)



(d)

Figure 2. Speckle patterns and interference fiber, (a), (b) Spatial distribution of two speckle patterns before interference; (c) interference pattern of two patterns similar speckles, and (d) removing interference pattern with speckle by radial fiber vibration frequency of 50 Hz.

In Figure 3 the interference pattern appears speckles is shown using two different types of multimode fibers. Fig. 3 (a) shows the interference using a silica fiber with gradient index core of diameter 50 μm length 3 meters. One can see that the interference pattern is quite stable because it contains fewer modes (tens of modes) and height of speckle are larger, also the rigidity of glass material makes them more stable than fiber based polymers. In Figure 3 (b) interference speckle pattern obtained is shown with a multimode plastic optical fiber based PMMA with core diameter of 980 μm and a length of 20 meters. The amount of speckle (hundreds of thousands of modes) is observed well distributed spatially. Although the length of the fiber and the large number of modes, the interference fringes are observed. This can be attributed to the high coherence length of the laser and which also has a degree of polarization of the beam spread in the fiber.



(a) (b)

Figure 3. Interference patterns obtained in two different multimode fibers. (a) multimode fiber graded-index of silica of 50 μm core diameter, and (b) multimode plastic fiber PMMA step-index of 980 μm core diameter.

4. CONCLUSIONS

Experimentally studying the polarization state of speckle in multimode fiber, it was observed that the speckles individually retain its polarization state spatially some distance from the outlet end of the fiber. Using a Michelson interferometer assembly interference speckle pattern it is made and a new interference pattern is obtained. Multimode fibers were studied with gradient profiles of the index and step index 3 and 20 m in length, resulting interference patterns in all of them. Each bright strip retains the speckles and their sensitivity to perturbations of the fiber, but the set of (bright and dark) stripes remain insensitive and are very stable. In addition, speckles can be removed by vibration of the fiber in radial direction. These new degrees of freedom of speckle in multimode fibers and interference offer new opportunities for applications in sensors and optical metrology.

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