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Temporal dispersion induced commercial laser in speckle free intense imaging

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ABSTRACT

Coherent imaging suffers from speckle, which is basically some uncorrelated intensity distribution and bears no obvious relationship to the macroscopic properties of the object illuminated. Reducing the spatial coherence of the illuminating beam, usually improves the quality of imaging by paying the penalty for reducing intensity, and directionality as well. Here, we demonstrate an alternative way of resolving the speckle issue by inducing temporal dispersion onto the commercial He–Ne laser beam, devising with a dispersive slope available near to the edge of the 1-D organic photonic band gap Cholesteric Liquid Crystal (CLC).

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In vivo, high resolution, non invasive optical imaging technology provides a means to interfere the light in the image plane (2-D imaging) and hence detects the phase map of an object of interest. Biological samples are usually of thicker and scattering type, and because of that probe beam intensity degrades rapidly in thicker samples. This gives rise to the essence of employing high intense commercial laser source in imaging technology. Moreover, for some ultrafast imaging purposes, for example extremely short life photochemical process, where overexposed light could be harmful or, for behavioral study of some physical parameter in real time etc., where controllability over laser makes it an indispensable light source. However laser produces speckle, which is very well known coherent artifact [1] in the coherent imaging system, basically produced by random environmental index variation in the test sample when illuminated by coherent light source (narrow band laser). The wave, reflected or transmitted from such a medium consists of so many de-phased but coherent wavelets, results in a way of very fine and irregular intensity distribution over the image. A tremendous effort is being attributed to reduce this speckle by reducing the spatial coherence of laser beam [2–4]. Few researchers proposed some typical lab made broadband laser to have low spatial coherence and hence reduction in speckle [5]. Employing some extra diffuser to the broadband dye laser to randomize the beam further, reaches another level of improvement in speckle reduction by paying the penalty for reducing intensity as well as destroying the directionality of the probe beam [6]. In this letter, we have reported that the issue of speckle in coherent imaging can be suppressed, even in commercially available He–Ne laser without raising any issue with intensity and directionality, by introducing temporal dispersion in the probe beam of He–Ne laser. We devised the dispersion by using the dispersive slope available at the edge of 1-D organic photonic band gap Cholesteric Liquid Crystal (CLC) [7,8].

The coherence volume as depicted in Fig. 1(b) is usually defined as the product of temporal coherence length (l_c) and the area of spatial coherence (λ^2) [9,10]. Two points on a plane parallel wave front can interfere if they are spatially separated by multiple of wavelength (λ). For a partially monochromatic source like He–Ne laser the spatial coherence length is very large. Furthermore, because of its narrow bandwidth its temporal coherence length is very high typically around 20–30 cm [11]. Inside the coherence volume, all the de-phased photons (assembly of bosons; *B–E* statistics) of different constituting longitudinal modes ($\lambda 1$, $\lambda 2 \ldots$) are degenerate in terms of energy [9]. As a result the energy band (ΔE) is very narrow for this partially monochromatic laser source and the uncertainty relation ($\Delta E.\Delta t = 1$) leads to very high temporal coherence (Δt). There are two ways to reduce the coherence volume and hence the photon degeneracy for coherent artifact (speckle) free imaging. Firstly, employing a well engineered rough surface (diffuser) to reduce the spatial coherence length [12–14] but, while imaging through turbid medium or thick biological sample, the medium itself provides the scatterers, by default. In that case, employing some extra diffuser in the probe beam for reduction in spatial coherence is needless if the medium (to be imaged) has sufficient scatterers to have the phase excursions comparable with 2π rad [1], and moreover extra diffuser reduces

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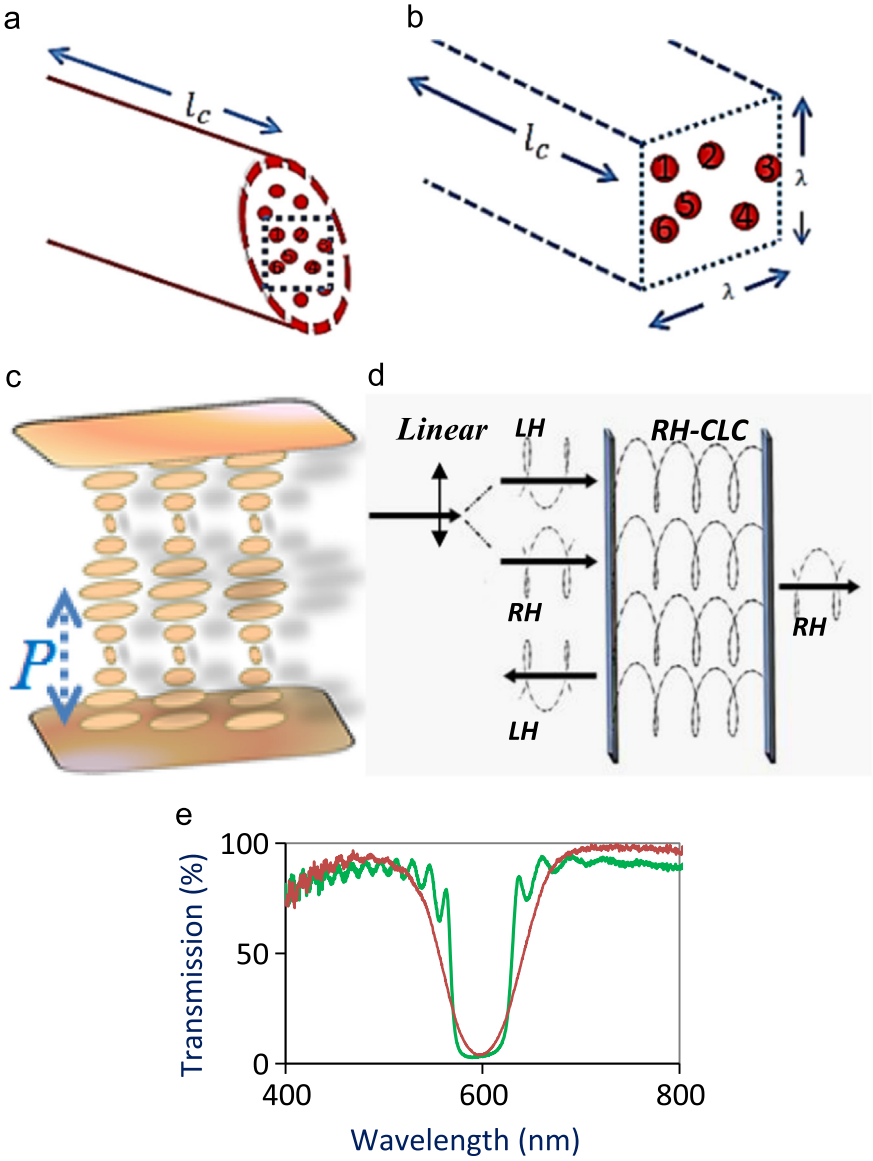

Fig. 1. (a) Schematic diagram (not to scale) of the cross-section of a laser beam showing temporal coherence length (l_c) and high density of photon (red circles); (b) magnified version of the rectangular section of fig.-a, the coherence volume ($\lambda^2.l_c$): where the circular points illustrating the de-phased but coherent photons of corresponding modes ($\lambda 1,\phi 1$),…,($\lambda 6,\phi 6$). (c) periodic arrangement of CLC molecular system, because of its periodicity ($\lambda = n_{avg}.P$ and $\Delta\lambda = \Delta n.P$) of the order of optical wavelength, it reveals a photonic bandgap as in (e); (d) ray diagram of the CLC system: helical periodicity of the CLC decomposes linear polarized incoming wave into two circularly polarized components L.H. and R.H., while R.H. transmits through right handed CLC (RH-CLC) and L.H. reflected back (e) very pronounced 1-D photonic band gap by using two opposite handed CLC cells to reflect back both L.H. and R.H. red: slow dispersive slope caused in absence of alignment layer in the cells, green: with alignment layer, which is used to improve the arrangement of CLC molecules, hence fast slope to induce higher temporal dispersion. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the output intensity. Secondly, inducing temporal dispersion (which we demonstrate in this letter) reduces the temporal coherence (Δt), hence does the coherence volume and the energy band ΔE becomes well resolved. Sufficiently high resolved ΔE enables all constituting modes to be de-correlated and provides enough diversity in longitudinal modes of the probe beam [9,10].

The CLC possesses a supramolecular helical periodic structure (Fig. 1(c)). Having this unique property of dielectric periodicity and being possible to make the periodicity of the order of optical wavelength, incoming rays sense the helical periodicity parallel to the helix axis inside the CLC medium, which forms a standing wave and opens up one dimensional (1-D) forbidden band gap over the corresponding range of optical wavelength. Because of the helical nature of periodicity linear polarized light decomposed into two circularly polarized components, left handed (L.H.) and right handed (R.H.) as shown in (Fig. 1(c)). Well inside the bandgap optical modes, spontaneous emission, and vacuum fluctuation all are absent [15–17], but more and more we move away from the central wavelength (λ_C) of the bandgap, the medium offers inappropriate periodicity very regularly (because of high packing density of supramolecular arrangement) to the available longitudinal modes and behaves as a temporal dispersive medium [7,8]. Single handed CLC-helix provides the dispersion only to the same handed circularly polarized light, while it passes through but, opposite handed circularly polarized light remains un-dispersed, which necessitates the use of both handed (R.H. and L.H.) CLC cells. The final output is elliptical because few amount of light is reflected back from the periodic layers of the CLC.

In order to induce this natural dispersion, We have used the CLC cell stack (R.H. and L.H.) purposely, as described in the above paragraph. We have used the liquid crystal E7 (Δn=0.21), mixed with right handed chiral dopant R-811 and left handed chiral

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