Polychromatic polarization: new label-free imaging capabilities in biology, medicine, geology, and data storage

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Abstract

Conventional polarizing microscope employs the Newton interference colors generated by two white light beams with relative retardance from 300 nm to 1800 nm. The image hue is determined by the retardance amount and the image brightness is determined by orientation of the slow axis. However, most of biological structures have retardance well below 300 nm. Therefore, under such microscope, they are seen as weak grey images, and their contrast disappears at certain orientations. Recently we proposed a polychromatic polarizing microscope (PPM), which employs the vector interference of polarized light [1, 2]. The PPM generates the full spectrum colors at retardance of several nanometers, which was not possible before. The previously colorless birefringent images of organelles, cells, and tissues become vividly colored at any specimen orientation. The image hue in PPM is linearly proportional to orientation of the slow axis, and the image brightness is determined by the retardance amount.

We will report on the latest developments in PPM. It was proven that PPM is a necessary tool for visualization of weak optical anisotropy, which could be used in many areas of biology, medicine, biotechnology, and pharmacy. Here are some examples of applications of PPM: (1) Imaging of collagenous stroma allows to visualize a cancer invasion without need of special stains. A combination of PPM technology and artificial intelligence will create a new promising tool for cancer diagnosis and prognosis. (2) PPM offers significant improvements for the diagnosis of arthritis and rheumatism [3]. The PPM user can see monosodium urate (MSU) and calcium pyrophosphate (CPP) crystals clearly, while a regular microscope obscures crystals with some orientation. (3) The malarial pigment, hemozoin, which is a crystalline product of the digestion of hemoglobin by the parasites can be easy detected by PPM. (4) The microscope can be used in various brain studies without need to apply chemical treatment or staining to the specimen. Nerve cells will appear in the real colors that reveal orientation of the molecules. PPM image shows how these cells are interconnected. Such information is critical for learning more about how a brain works or about what might be going wrong with those interconnections during Alzheimer's disease and other neurological conditions. (5) Visualization of meiotic spindle in human and animal oocytes is critical during in vitro fertilization (IVF).

PPM can also be used in geology, where it allows detection of non-isotropic minerals with very low birefringence (e.g., garnet) by observation of conventional 30-μm petrological thin-sections [4]. It is valuable also in optical data storage for reading information recorded by birefringent voxels in silica glass [5]. Information in voxels is written by two parameters: retardance (brightness) and slow axis orientation (hue).

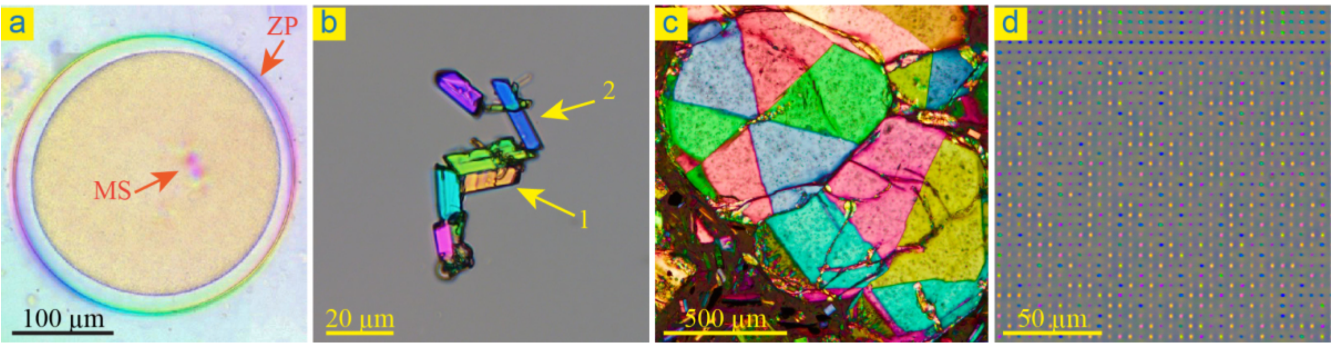

Figure 1. (a) Sea star oocyte in metaphase II. Meiotic spindle MS and zona pellucida ZP are clearly visible. Spindle retardation is about 1 nm. (b) Cluster of CPP crystals. Crystals 1 and 2 are invisible under conventional polarizing microscope due their orientations. (c) Igneous cordierite crystal with six-sector trilling twins in dacite. (d) Birefringent voxels in silica glass slab, which contains 42 information layers. Each voxel records 4 bits of information: 2 retardance levels, 1 nm and 2 nm, and 8 slow axis orientations, from 0º to 180º with step 22.5º.

References

1. M. Shribak, ""Polychromatic polarization state generator and its application for real-time birefringence imaging", US Patent 9625369 (2015).
2. M. Rajabi, O. Lavrentovich, and M. Shribak, "Instantaneous mapping of liquid crystal orientation using polychromatic polarizing microscope", Liquid Crystals, 50, 181-190 (2023).
3. H. Jum'ah, M. Shribak, A. Keikhosravi, B. Li, Y. Liu, D. Obaidat, K.W. Eliceiri, A. Loeffler, S. Ayub, " Detection of crystals in joint fluid aspirates with polychromatic polarization microscopy", Annals of the Rheumatic Diseases Journal. 82,1501-1502 (2023).
4. B. Cesare, N. Campomenosi, and M. Shribak, "Polychromatic polarization: boosting the capabilities of the good old petrographic microscope", Geology, vol. 50, No. 2, 137-141 (2022).
5. M. Sakakura, Y. Lei, L. Wang, Y. H. Yu, and P. G. Kazansky, "Ultralow-loss geometric phase and polarization shaping by ultrafast laser writing in silica glass," Light Sci. Appl. 9, 15 (2020).