Differential interference contrast microscope based on birefringent shearing interferometry

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Introduction. Since differential interference contrast microscopes (DICMs) are able to enhance the contrast of object images, they are now widely utilized in live cell imaging, silicon semiconductor processing analyzing, roughness inspection, etc. Basically, DICMs enhance image contrast by retrieving the interference pattern of two laterally sheared wavefronts from the sample, and several designs have been developed successfully for this objective. The 1st one uses a Nomarski prism (or a pair of Nomarski prisms)\(^{(1-4)}\), the 2nd utilizes a Savart prism\(^{(5)}\), and the 3rd adopts a Sagnac interferometer\(^{(6)}\) as device for shearing the wavefront. However, for eliminating the wavefront distortion introduced by the objective, these designs require extra equipment to ensure measurement quality.

For instance, the 1st design employs a collimator to adequately collimate the light wave incident on the Nomarski prism. The 2nd and 3rd designs not only use a collimator to collimate the light wave from the source, but also replace the objective by an afocal microscopic system to collimate the light wave incident on the sample. Although some other designs of DICMs have been developed\(^{(5)}\), the corresponding systems are still complicated due to the same season for removing wavefront distortion brought in by the objective.

Configuration and measurement theory. A novel microscope as that shown in Fig. 1 is proposed for surmounting the abovementioned problem. It is found that this microscope is the same as a conventional polarizing microscope except the Savart prism, whose principal section makes an angle of 45° with the x-z plane, placed between the objective and sample. The Savart prism therefore laterally shears the light wave from the objective into two linearly polarized waves having shear direction along the x-axis and vibration directions along x-axis and y-axis, respectively, and it then recombines the sheared waves reflected by the sample.

![Fig. 1: Apparatus of the proposed microscope; where CF: color filter, P: polarizer with transmission axis at 45° measured from the x-axis, BS: beam-splitter, SP: Savart prism, λ/4: quarter-wave plate with fast-axis at 45° measured from the x-axis, A: analyzer with transmission axis at 0° measured from the x-axis and rotation axis parallel to the z-axis](image)

The recombined beams then travel through the objective, beam-splitter, quarter-wave plate, and analyzer to generate a shearing interference pattern on the CCD sensor. A derivation and a numerical calculation regarding this pattern have been done, the results prove that the intensity of the interference pattern has a form of

$$I = I_0(1 + \gamma \sin(\Delta \phi, +2\theta)); \quad (1)$$

where

$$\Delta \phi = \frac{4\pi}{\lambda_i} \Delta W(x,y) = \frac{4\pi}{\lambda_i} \frac{\partial W(x,y)}{\partial x} \Delta x; \quad (2)$$

and \(\lambda_i, W(x,y), \) and \(\Delta x\) in Eq. (2) represent central wavelength of the light source, contour height of the sample, and shear distance, respectively.

This convinces us that the proposed microscope is a DICM. Since, as conventional DICMs, it is able to acquire DIC images (i.e. images of Eq. (1)) by just recording the patterns on the CCD sensor and extract phase-DIC images (i.e. images of Eq. (2)) by phase-shifting algorithms. Note the phase-shifting images for the phase-shifting algorithm are the DIC images with different phase bias, i.e. 20.

Experiments and experimental results. A setup of the proposed DICM was installed and then conducted to retrieve the DIC images and phase-DIC image of a VLSI step-height standard and a sample of endothelial cell, the results agree the validity and feasibility of the proposed DICM.

To get the images with shear direction along the y-axis, the DICM can just rotate the Savart prism about the z-axis by 90° and then repeat the same process of x-direction measurements; this function has already been verified using experimental results. To enhance the DICM so it is capable of both reflection and transmission inspections, an another set of Savart prism, objective, quarter-wave plate, analyzer, and CCD sensor placed on the right-hand side of the sample is required, this function is now under study by the authors.

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