Confocal Scanning Laser Holography: A Tool for Non-Invasive Internal Measurement

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Confocal Holography is a combination of two well known concepts: confocal microscopy and light (laser) holography. Confocal microscopy places an aperture at a conjugate focus to the specimen focus. This filters any rays that are not on the focus plane, allowing a 3-dimensional image of the specimen to be built up over a set of planes.

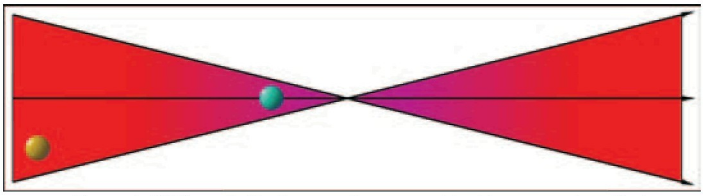

Figure 1: Differential influence; the green object has a greater effect on the beam than the gold one.

Holography is the measurement of both the amplitude and phase characteristics of light. Typically most methods only measure the amplitude of the image. The phenomenon of interference allows the determination of the phase shift for a coherent source as well. The phase information is directly related to the index of refraction of a material, which in turn is a function of the temperature and composition.

$$\Delta\phi = d\Delta n(T,C)$$

$$\Delta n_{T+C} = \left(\frac{\partial n}{\partial T}\right)_C + \left(\frac{\partial n}{\partial C}\right)_T$$

For an experiment with multiple variables, multiple data sets for the index of refraction can be gathered for different wavelengths, and then solved to simultaneous determine temperature and multiple compositional variables. This makes confocal holography a potential method for non-invasively determining internal characteristics of materials, such as temperature, mixing, solute gradients, *etc.*

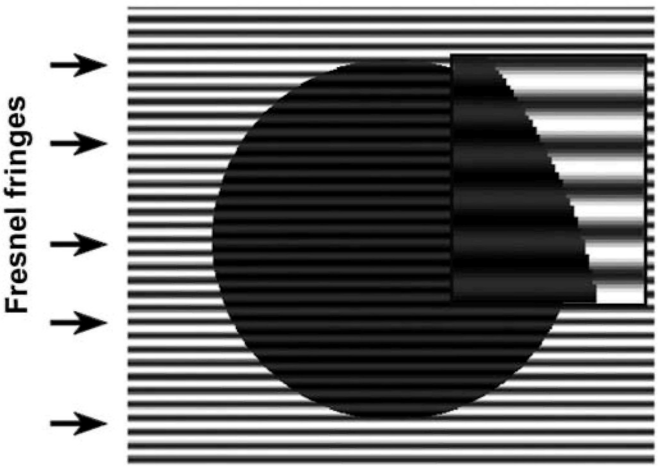

Figure 3: Computer simulation of a bubble, with a fringe shift at the interface showing faint Fresnel fringes due to being out of focus.

The basis for the determination of the phase shift in 3-dimensions is the non-uniform influence objects at different points along the optical axis have on the hologram (Figure 1). Objects that are closer to the focus will influence a greater number of rays. As the focus is rastered through the object, the influence of individual volume elements – voxels – within the specimen volume will change. The hologram is windowed into sections that allow the tracing of individual rays that are incident on the window through the specimen. Thus it is possible to construct, in a computer, a 3-dimensional map of the phase shift created by the specimen. This is in contrast to a collimated beam, where only the integrated through phase shift can be determined.

The confocal laser holography microscope design (Figure 2) under development at the University of Victoria is based on the Dixon confocal microscope [2]. Through a polarization method it can operate exclusively in transmission or reflection mode. It uses a wavefront splitting mechanism to create the reference beam; this increases the complexity of the optical system but allows the exact phase shift to be determined for weak phase objects (*i.e.* such that $\Delta\phi < 2\pi$) because the path length of the specimen and reference waves is the same. In cases where the phase shift is greater than 2π by a small amount, phase unwrapping techniques may be applied to determine the absolute phase shift.

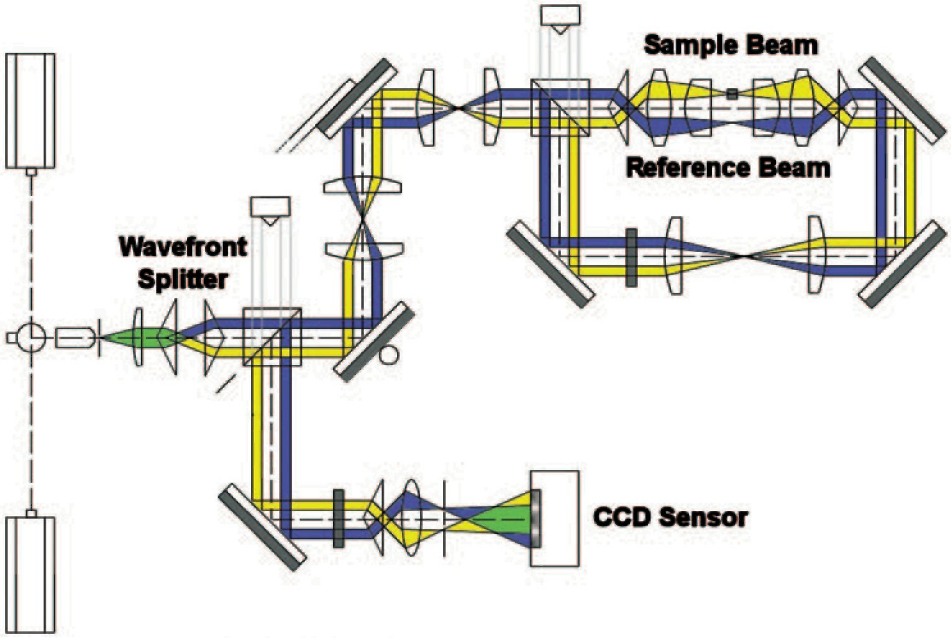

Figure 2: Layout of confocal holography microscope.

This design also uses scanning mirrors to raster the beam through the specimen. This allows the specimen to remain stationary, which is important for fluid experiments. The scanning volume is approximately 5 x 5 x 5 mm. The optical loop ensures that the pupil on the double pinhole aperture remains stationary.

In order to better characterize the confocal holography microscope, a simulation program is being developed to investigate the expected results from certain specimen geometries. In particular this is useful for examining the effect of scattered rays on the fringe pattern of the hologram. In a simulation of a small bubble (n=1.0) in glass (n=1.5) we can see the formation of multiple fringe patterns (Figure 3). There are three interference patterns formed between three beams: the reference wave, the specimen wave that passes by the bubble, and the specimen wave that passes through the bubble and is scattered by it, forming Fresnel fringes. The bubble forms a shadow on the image because most of the incident light is refracted off the detector plane. Note that this bubble is a strong phase object ($\Delta\phi >> 2\pi$).

As a technique, confocal holography holds promise to better characterize many physical processes in materials science, such as combustion and convection. It also may contribute to the biological sciences by imaging low-contrast, weak-phase objects. Thanks to the ongoing, continued improvement in computer processing speed, it has recently become practical to interpret data from confocal holography microscopy with a computer. We hope that, in the future, confocal holography will become as popular a method for measurement as its namesakes. ■

References

1. RA Herring: Confocal scanning Laser holography, and an associated microscope: a proposal. Optik 105 No. 2 (1997) pp. 65-58.
2. AE Dixon, S Damaskinos, MR Atkison: A scanning confocal microscope for transmission and reflection imaging. Nature 351 (1991) pp. 551-553.