Evanescent imaging with induced polarization by using a solid immersion lens

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Image contrast enhancement, high lateral resolution, and height information are obtained with induced polarization evanescent imaging using a solid immersion lens. Experiments are conducted by imaging features on a patterned Si substrate. Imaging theory is used to predict optimum orientation of high-spatial-frequency samples, and a topographical image is derived from the induced polarization image through a calibration procedure. A numerical aperture of 1.5 is used in the experiment. Height accuracy of ±2 nm is demonstrated with a known sample. © 2006 Optical Society of America

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A solid immersion lens[1,2] (SIL) has distinct advantages over liquid immersion systems, in that the sample is not affected or contaminated by the liquid and the numerical aperture (NA) can be greater than 2.0. The work reported here concerns development of an induced polarization evanescent imaging technique using a SIL that can achieve nanometer vertical resolution with high lateral resolution and provides for real-time imaging over a relatively large field of view. Although far-field optical interferometric profilers can provide nanometer vertical resolution, the lateral resolution is limited by NA<1 in air.[3]

The SIL is a high refractive index, image-centric hemisphere, as shown in Fig. 1. A small gap between the flat side of the hemisphere and the object provides a path for evanescent coupling of light between the SIL and the sample. NA in this case is equal to $n \sin \theta_m$, where n is SIL's index of refraction. Lateral resolution is improved by a factor of n in the SIL system compared with using the same objective lens in air. The air gap height h must be very small ($<\lambda$) for evanescent coupling to occur.

Recent experiments have demonstrated that characteristics of an induced polarization signal from a SIL system illuminated with a coherent laser beam can be used to measure and control the gap spacing h to better than ±2 nm over a fast moving substrate.[4] Measurement of the gap control signal is illustrated in Fig. 1 using a 650 nm laser beam as the illumination source, which passes through a linear polarizer that establishes the *native polarization* state in the plane of the figure. After reflection from the nonpolarizing beam splitter, the native light is focused by the objective lens into the SIL. Upon reflection from the SIL's flat surface, the phase and amplitude differences between p and s polarization states produce an *induced polarization* state at the pupil of the objective lens that is orthogonal to the native polarization state.

The induced polarization energy is integrated onto a photodiode (PD) with a front polarizer oriented perpendicular to the native polarization. A plot of the calculated and measured gap-induced polarization signal S for a flat glass sample and Si sample with laser illumination is shown in Fig. 2. In this case, the sample must be flat and uniform over the area of the focused laser beam, which is approximately 430 nm in diameter. The simulation model is based on a vector plane-wave decomposition of light emitted from the exit pupil.[5–7] Light emitted from each sample point in the exit pupil reference sphere arrives as a vector plane wave at the flat side of the SIL inside index n. The vector interaction of each plane wave with the thin-film stack composed of the incident index n, air gap, and homogeneous thin-film structure of a reference object is governed by known thin-film relationships.[8] The reflected power of the gap-induced polarization component changes monotonically with air gap height, and it is very stable. However, it is dependent on substrate material, as shown in Fig. 2, which also shows the reflected-light distribution at the collection pupil from a CCD camera refocused to image the pupil of the objective lens for two values of h.

The new aspect of the system reported in this paper utilizes the gap-dependent property of the induced polarization signal, but, instead of a laser beam, the illumination light is derived from a stan-

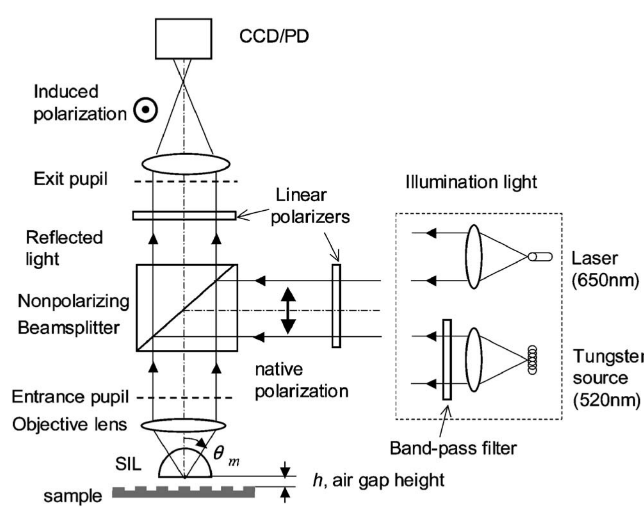

Fig. 1. Schematic of a SIL microscope that includes an induced polarization gap measurement system and an evanescent imaging system.

