Nanometer-level Alignment and Global Positioning to a Substrate-Embedded Coordinate System

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Previous work demonstrated nanometer-level overlay of imprinted patterns using Interferometric-Spatial-Phase Imaging (ISPI) alignment [1]. ISPI was also used to position an AFM tip with nanometer-level precision [2]. In both cases, position was detected by spatial-phase analysis of complementary sets of interference fringes, resulting from coherent illumination of localized marks on two facing surfaces, such as, the lower surface of a template and the front surface of a substrate.

In this paper we describe a method for acquiring position information continuously at any location across a large-area IR-transparent substrate using a checkerboard pattern that spans the backside of the substrate, as illustrated in Fig. 1(a). Infrared illumination ($\lambda > 1$ μm) readily penetrates silicon, and many other substrates. IR illumination of an interrogation mark (Fig. 1(b)), on a movable element above the substrate, results in a fringe pattern (Fig. 1(c)) that enables sub-nanometer detectivity of position at arbitrary locations across the substrate.

This method provides long-range, accurate X, Y, and θ position control of a template, as illustrated in Fig. 2. In a related configuration, this method supports globally-referenced, nanometer-level control of multiple scanning tips. Tip positions can be controlled individually, without intrusion of alignment marks on the patterning surface. Since the substrate mark does not reside on the front side, it can be employed as a spatial reference during multiple process steps, or between multiple tools, with utility in high-precision, multi-layer alignment. In addition, long-wavelength illumination is not incompatible with sub-nanometer detectivity, opening an avenue to nanometer-level alignment in wafer-to-wafer bonding for MEMS/NEMS.

In the paper, we describe in further detail infrared-based ISPI in an alignment system, efficient and accurate fabrication of the backside checkerboard mark, unambiguous spatial-phase measurements across a substrate, analysis of signal-to-noise levels, experimentally determined range of effectiveness, and multi-layer overlay statistics.

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[1] E. E. Moon, M. K. Mondol, P. N. Everett, and H. I. Smith, J. Vac. Sci. Technol. B **23**, 2607 (2005).
[2] E. E. Moon, J. Kupec, M. K. Mondol, H. I. Smith, and K. K. Berggren, J. Vac. Sci. Technol. B **25**, 2284 (2007).

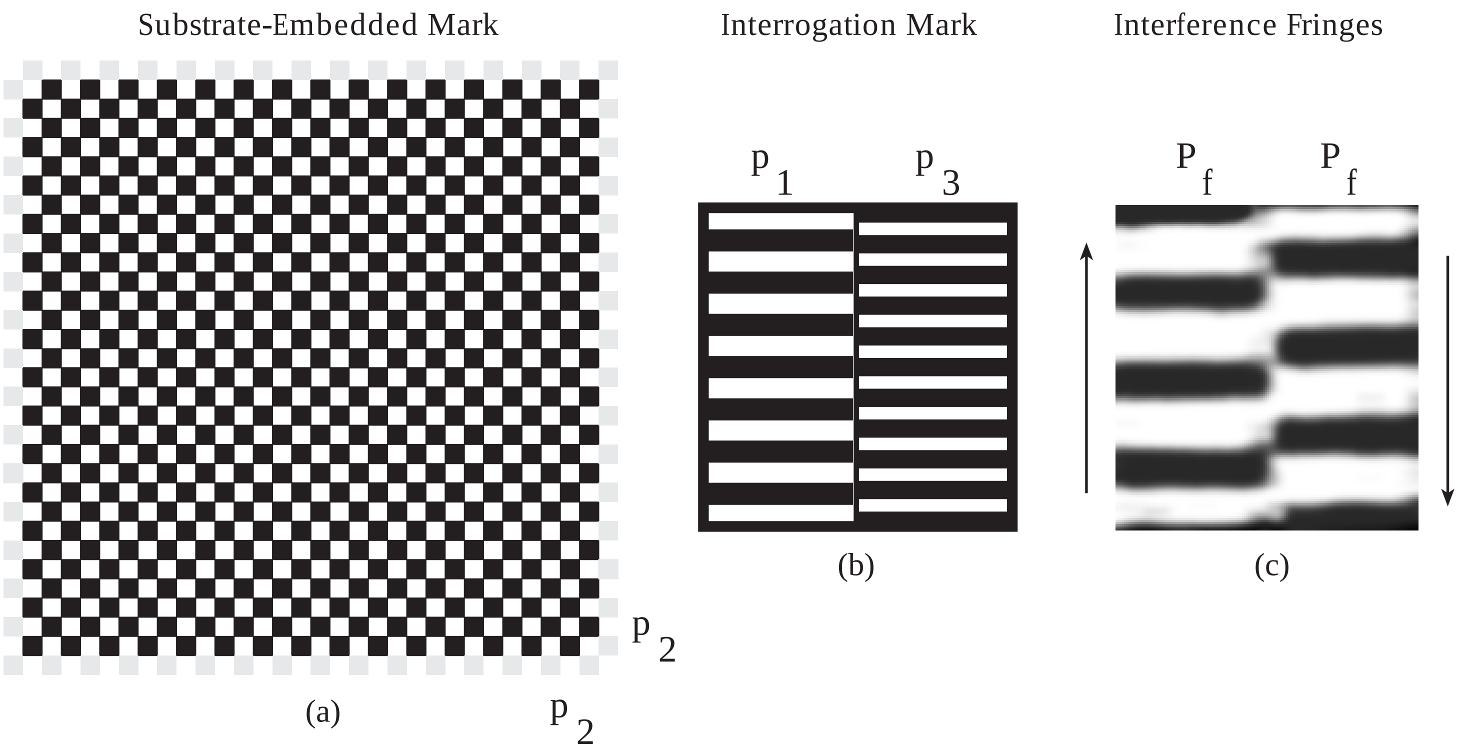

Fig. 1. (a) Schematic of an ISPI global checkerboard mark. The mark spans the backside of a substrate. (b) Schematic of an interrogation mark placed on a movable element above the substrate. (c) CCD image of interference fringes produced by coherent infrared illumination of the marks. Position is determined at the sub-nanometer level by analyzing the spatial-phase relation of the counter-moving fringe sets. Position measurements can be taken at any location above the substrate.

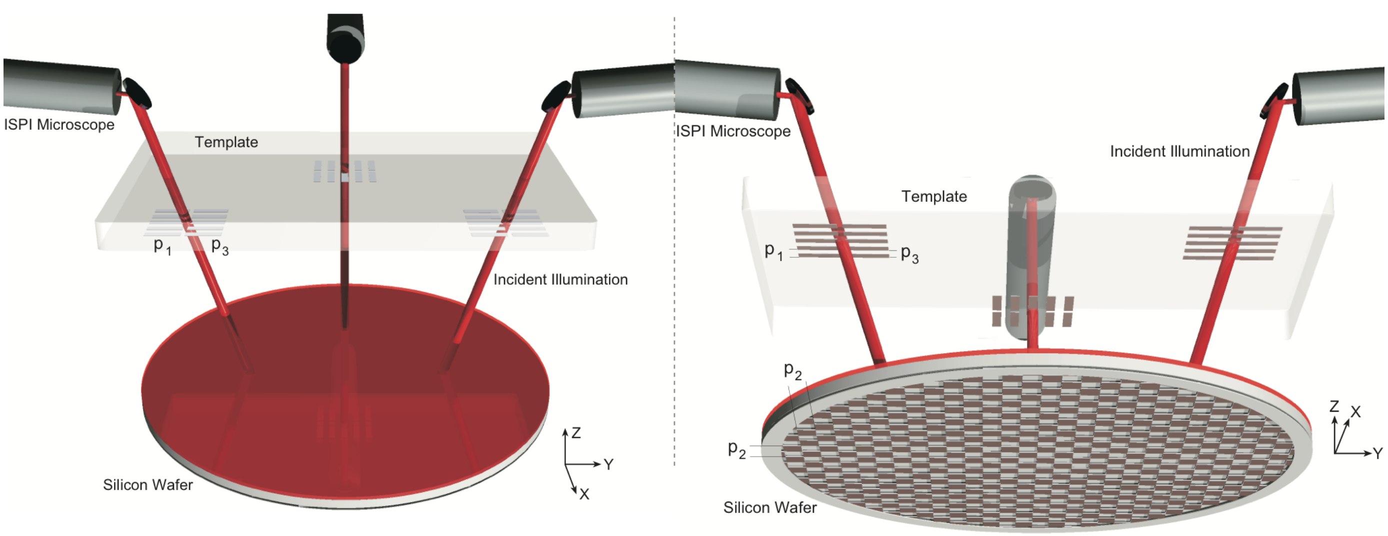

Fig. 2. Schematic views of a substrate with embedded ISPI marks, illuminated by coherent infrared light. No marks are required on the frontside of the substrate. In the depicted configuration, three ISPI microscopes interrogate position, two in X and another in Y, relative to the global backside checkerboard.