Photo-Masks Inspection for Defects in Integrated Circuits Using Optical Interferometer

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ABSTRACT - Defect inspection in one of most important and necessary activity in the manufacturing process of photomask. Unwanted deviation and defects in integrated circuits impact the performance of the chip. This paper presents a method which utilizing minimal optics for the process of extracting photomask defects using a Lloyd mirror interferometer. Experimental results and geometrical layout of interferometer used are present in paper.

Keywords – Photo-Masks, IC, Interferometer.

I. INTRODUCTION

In semiconductor industry there is a growing demand for fast defect-inspection of large and fine periodic patterns (such as photo-masks, wafers etc). Manual inspection process is slow, tedious and costly, leading to excessive scrap rates and does not ensure high quality and also the production rates for high-tech industries are so demanding that manual inspection is not feasible. There are many digital methods for automatic defect inspection [1-6]. Digital techniques generally involve the bit-by-bit or pixel-by-pixel comparison of information associated with reference and test patterns. These methods require sophisticated algorithms and are time consuming for patterns with larger size and hence may not be a good candidate for fast detection. In order to overcome this, various optical methods based on holography and nonlinear spatial filtering, have been reported in the literature [7-9]. These methods offer significant advantages of fast and parallel processing over digital methods but require photorefractive crystals or polarization sensitive organic materials and complex configurations that limit processing time. Some simple optical methods based on schlieren techniques [10], Talbot interferometry [11] Holographic optics based interferometers [12-14] and moiré techniques [15] are available in literature for optical studies and for defect enhancement. Though these configurations are simple as compared to earlier methods but generally require large number of optical elements. In this paper we describe an alternative method for defect inspection of periodic patterns requiring fewer optical elements as well as providing an in-built phase stepping facility for pattern-substrate/surface flatness testing [16]. Lloyd mirror interferometric fringes are superimposed onto the test pattern to generate finite-mode moiré, which could be converted into null-mode moiré by proper tuning the spatial frequency of interferometric fringes. This null-mode moiré provides direct visualization of test pattern defects.

II. THEORY

The Lloyd mirror interference pattern can be written [17]:

$$h(x,y) = a(x,y) + b(x,y) \cos[2\pi f_o x], \quad (1)$$

where a(x,y) is a background intensity, b(x,y) is the fringe modulation, and $f_o = d/\lambda s$ is a spatial frequency of the interferogram. Spatial frequency f_o could be tuned either by changing distance d between two point sources or by changing wavelength λ of the light used or by changing distance s, separation between the plane of two point sources (focal point and its virtual image) and the observation plane (Fig.1). The transmittance of a periodic test pattern oriented at an angle θ with respect to y-axis and having defects e.g. hairs, dust particles or scratches can be written as [5]

$$t(x,y) = [1 - f(x,y')]t'(x,y) + s(x, y''), \quad (2)$$

where $f(x,y')$ represents the effect of a hair characterized by the curve $y = y'(x)$; $s(x, y'')$ is the effect of a scratch that describes the curve $y = y''(x)$ and $t'(x, y)$ represents transmittance of the test pattern without defects given by

$$t'(x, y) = c_0(x,y) + c_1(x,y) \cos[2\pi f_1 (x \cos\theta - y \sin\theta) + \delta(x,y)], \quad (3)$$

where c_0 and c_1 are constants depending on the test pattern parameters, f_1 is spatial frequency of the test pattern, $\delta(x, y)$ is phase factor due to substrate/surface flatness. Here higher order harmonics have been neglected for

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mathematical simplification. The intensity distribution due to superimposition of interferometric fringes onto the test pattern will be equal to the product of the interferogram intensity and the test pattern transmittance [15]:

$I(x,y) = t(x,y).\ h(x,y)$

$= [\{1 - f(x,y')\}c_0 (x,y) + s(x, y'')]\ a(x,y)$

$+ [\{1 - f(x,y')\}c_0 (x,y) + s(x, y'')]\ b(x,y) \cos[2\pi\ f_o\ x]$

$+ [1 - f(x,y')]a(x,y)\ c_1(x,y)\ \cos[2\pi f_1 (x \cos\theta - y \sin\theta) + \delta(x,y)]$

$+ (1/2)\ b(x,y)\ c_1 (x,y)\ [1 - f(x,y')]\cos \{2\pi x (f_0 + f_1 \cos\theta) - 2\pi y\ f_1 \sin\theta + \delta (x,y)\}$

$+ (1/2)\ b(x,y)\ c_1 (x,y)\ [1 - f(x,y')]\cos \{2\pi x (f_0 - f_1 \cos\theta) + 2\pi\ y\ f_1 \sin\theta + \delta (x,y)\}$ (4)

The first term in Eq. (4) is a dc term containing defects, second and third terms are the amplitude modulated carriers, fourth term represents a high frequency sum moiré pattern and the last term represents a low frequency difference moiré pattern generally used to observe moiré effects. This finite-mode could be converted into null-mode moiré by adjusting test pattern parallel to interferometric fringes ($\theta = 0$) and interferometric fringe frequency equal to that of the test pattern frequency ($f_0 = f_1$), which is suitable for direct visualization of defects (e.g. dust particles, hairs, scratches, missing or broken periods, voids and pinholes etc.) present in the test pattern. Figures 2(a) and 2(b) show defect enhanced images of dust particles and uncompleted or broken lines in the test pattern (a transmission grating with a pitch of ~ 6.25 lines/mm) respectively. The defect-enhanced image of a human hair and a dust particle placed on an opaque test pattern (a reflection grating with a pitch of ~ 6.25 lines/mm) are shown in Fig. 3. In addition to defect enhancement shown in Figures 2 and 3, the method also provides information about pattern-substrate/surface flatness. Typical results showing surface flatness error in finite-mode are shown in Fig. 4. Here suitable low pass spatial filtering is used to get good visibility fringes. Phase stepping could be performed by in-plane translation of the test pattern itself perpendicular to its lines for obtaining phase profile of the substrate/surface flatness using well-known phase measurement techniques[13].

The experimental arrangement for defect inspection using Lloyd mirror interferometer is schematically shown in Fig. 1. A polarized He-Ne laser beam is expanded by using a × 60-microscope objective MO. A Lloyd mirror M (20mm X 40mm X 2mm; SiO_2 protected front surface silver coated) is used to superimpose two halves of the same wavefront from MO to generate fringe frequency comparable with that of the test pattern TP in the observation plane OP. The test pattern is inserted at the location of the fringes and its position is adjusted to generate finite-mode as well as null-mode moiré pattern with the interferometric fringe pattern.

The results presented have been captured with a Canon S-50 Power Shot digital camera with 1024 x 768 pixel resolution and white balance settings.

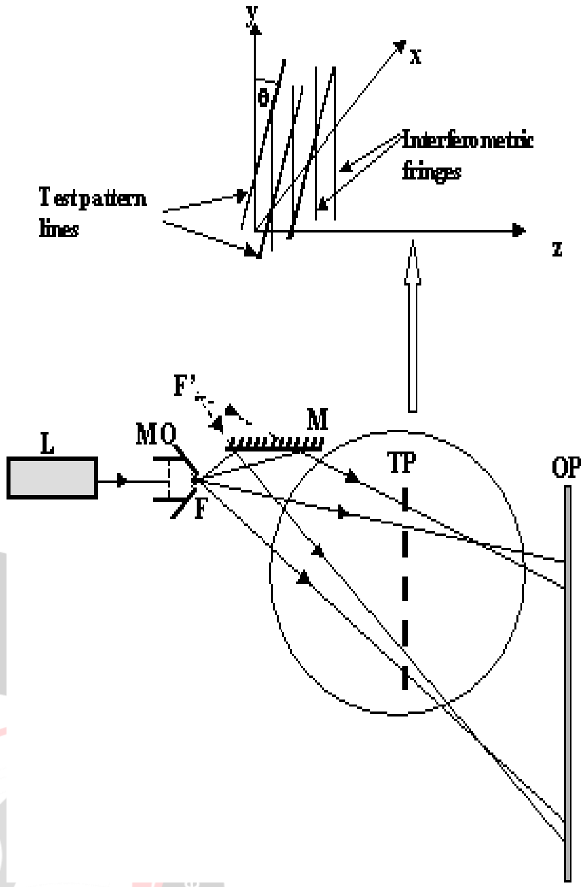

Figure 1. Schematic configuration of experimental setups for the inspection of periodic patterns

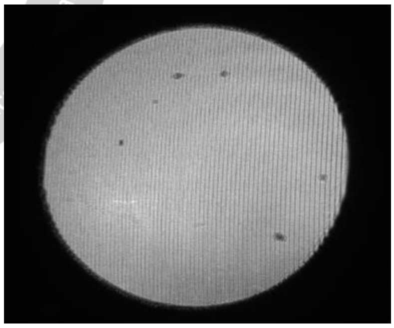

Figure 2 - Defect enhanced image of a transmission grating (a) dust particles

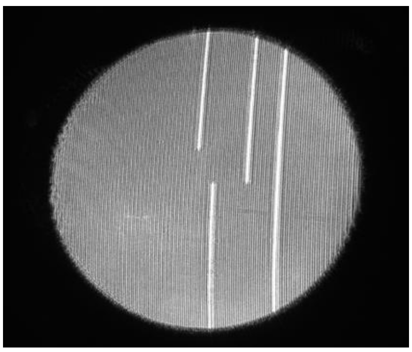

Figure 2 - Defect enhanced image of a transmission grating (b) uncompleted or missing periods patterns

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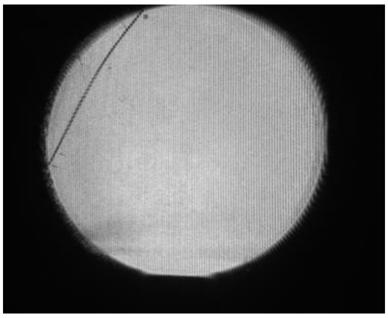

Figure 3 Defect enhanced image of a human hair and a dust particle placed on a reflection grating patterns

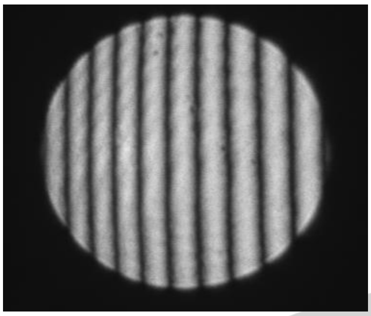

Figure 4 Typical finite-mode moiré pattern for testing the flatness of pattern-substrate/surface

III. CONCLUSION

we have realized a simple method for defect inspection in periodic patterns using Lloyd mirror interferometer. In addition to localize defects like dust particles, hairs, scratches, missing or broken periods etc., system also provides information about substrate/surface flatness with an in-built phase stepping ability. Varying spatial frequency of the interferometric fringes generated by the Lloyd mirror interferometer facilitates inspection of patterns with different frequency. Requirement of fewer optical elements, simple architecture and easy operation are the other highlights of the described method.

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