Optical difference engine for defect inspection in highly-parallel manufacturing processes

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Optical difference engine for defect inspection in highly-parallel manufacturing processes

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Abstract

Traditional defect inspection for highly-parallel manufacturing processes requires the processing of large measurement datasets, which is often not fast enough for in-situ inspection of large areas with high resolution. This study develops an all-optical difference engine for fast defect detection in highly-parallel manufacturing processes, where the detection of defects (differences from nominal) is performed optically and in real-time. Identification of defects is achieved through an optical Fourier transform and spatial filtering, detecting differences between two real objects by nulling information that is repeated in each object. The developed prototype device is demonstrated using geometric patterns of similar scale to components in printed electronic circuits.

1 Introduction

Current defect inspection methods used in highly-parallel manufacturing (HPM) of, e.g. printed electronics, coatings in solar cells, micro devices for medical applications, include mainly automated 2D optical imaging techniques with data processing methods, laser scanning methods and 3D scanning optical surface measurements techniques [1]. Defects such as microcracks in solar wafers can be detected using optical or near-infrared imaging technologies combined with image processing algorithms [2-6]. However, these types of techniques are limited by the computational speed when imaging large areas with high resolution. Potential 3D scanning optical surface measurements for HPM include optical coherence tomography (OCT) and wavelength scanning interferometry (WSI), which are based on interferometric techniques and broadband sources or tuneable lasers [7,8]. OCT and WSI offer high speed, high resolution and non-contact 3D measurement of surface features (and subsurface features by OCT). However, these techniques generate very large datasets from image stacks, and currently the data processing speed is too slow for in-situ defect inspection in HPM processes. Optical processing is an alternative to digital processing because it offers greater speed. Parallel optical processing by use of frequency domain architectures is potentially very fast, but often lacks flexibility and accuracy. The joint-transform correlation technique has been demonstrated as a useful tool for identifying defects in fabrics and optical fibres [9,10]. The coherent optical processing technique based on spatial filtering also offers high speed feature comparison and may be used for defect inspection in HPM [11]. In this paper, an optical difference engine (ODE) is developed using coherent optical processing techniques and demonstrated using simple geometries.

2 Principles and sensitivity analysis

Some types of signal computation, e.g. autocorrelation, spatial filtering, can be performed optically using Fourier optics in real-time. Utilising this advantage, the ODE is able to compute the difference between a perfect reference object and a test object with defects at high speed. A simple illustration of an ODE is shown in Figure 1. Two objects (t_a and t_b) positioned side by side are illuminated with coherent light and imaged with a 4f-system. An optical grating is placed at the *H* plane, where the real-space image of the two objects is transformed into the Fourier space. The grating performs spatial filtering in the Fourier plane before the image is transformed back into real space at the *U* plane, where the images of the two objects are overlaid and all the information repeated in both images is nulled, resulting in a single image containing only the difference between two objects.

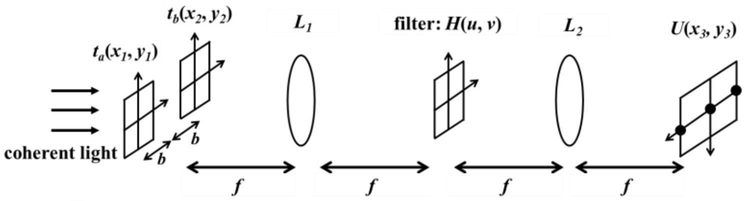

Figure 1: Illustration of an optical difference engine

A detector can be placed at the *U* plane to record the difference. As subsequent computation is kept to a minimum, the inspection speed is potentially close to the detector speed.

The main disadvantage of this ODE design is that high precision positioning of the optics is required as the alignment errors and grating period error causes shifting of the images of the two objects, resulting in poor registration and false detection. For example, Figure 2 shows the maximum allowed error in the grating period, within a range of focal lengths and grating periods, in order to keep the shift of images below 5 μm. Although the ODE is sensitive to alignment and grating period errors, the shift can be minimised through adjustment of the offset distance between the two objects.

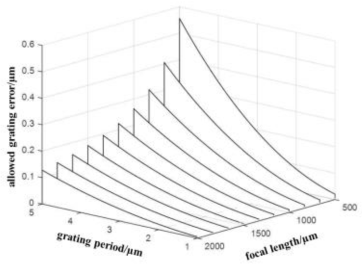

Figure 2: Allowed error in the grating period for the maximum central shift of 5 µm, assuming wavelength $\lambda = 0.5$ µm

3 Prototype optical difference engine

In order to implement the ODE without resorting to costly components, off-the-shelf products were used to build the prototype device. Table 1 lists the specifications of the core optical components in the prototype ODE system.

Table 1: Specifications of the optical components in the prototype ODE

Laser wavelength/nm	532	Laser beam diameter/mm	3.5
Grating type	blazed	Grating period/µm	3.33
Imaging lens focal length/mm	30	Image sensor type	CMOS
Image sensor colour	monochrome	Image sensor pixel size	1280 × 1024

Several practical challenges arose when building the prototype: (1) lack of suitable sinusoidal grating led to the use of a blazed grating with a saw-tooth shaped grating profile; the presence of blaze angle resulted in a refracted light path; (2) beam intensity homogeneity and dust on the built-in optics; (3) collimation quality of the light beam after expansion; (4) diffraction around the edges of the objects; and (5) compromise between lens size (cost) and effective field of view. These challenges were addressed by additional components and deviating from the setup in Figure 1. For example, a pinhole was used to improve the light intensity homogeneity and reduce speckle resulting from dust; the camera and imaging lens were re-positioned to comply with the modified light path due to the blazed grating; and the offset distance between the two objects was adjusted to compensate for manufacturing and alignment error in the grating. Figure 3 shows the setup of the developed prototype device.

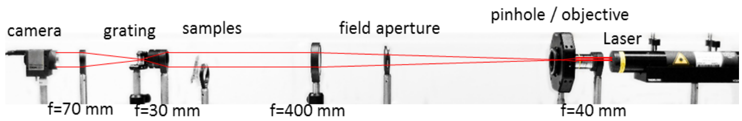

Figure 3: Setup of the prototype ODE system

Figure 4 presents the inspection result using the developed ODE system by comparing a rectangular pattern and a circular pattern cut from a thin steel sheet, representative of geometric features of printed electrical circuits produced with

HPM processes. Small defects are present on the edges of both patterns as seen in the figure.

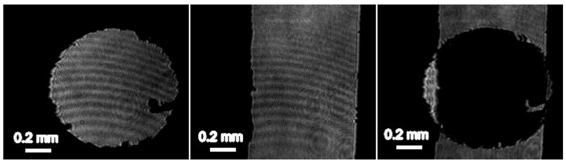

Figure 4: Inspection result comparing a rectangular bar with a hole. Images of a hole of Φ1 mm (left), a rectangular bar of 0.8 mm width (middle) and the optical difference of two objects (right).

In the resulting difference image, the common area present in both objects is nulled and shown as a dark area. The geometrical irregularities on the edge of the circular and rectangular patterns can be observed, as well as misalignment of the two patterns' centres. Defects as small as 30 µm can be detected.

4 Conclusion

An ODE system has been developed and implemented using off-the-shelf components and demonstrated with geometric patterns cut from a thin sheet. Preliminary result suggests that 2D ODE is a promising tool for the high resolution defect inspection in HPM processes. Data post-processing is minimised by conducting optical processing and the speed of the ODE is potentially limited by the sensor acquisition time. Further research efforts will focus on a parallel sensor setup to inspect larger areas and improvement of imaging quality.

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