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Extended Abstract

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Investigation of a high-resolution optical inspection system for fabricated metallic nanostructures using structured illuminations

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Optical measurement methods are widely employed in both industrial and medical fields for two reasons: optical methods are non-invasive and have a high resolution. Among various optical methods, the method based on spectroscopy is actively applied in monitoring multiple factors from spectral information. Optical microscopes can overcome the disadvantages of these traditional methods to analyze nanoscale components, but they are flawed by diffraction limits that limit imaging resolutions to a few hundred nanometers. To overcome the shortage, post-processing techniques such as deconvolutions were employed, but there were also limitations. Meanwhile, several studies of optical profile inspection systems using confocal or patterned illuminations were also progressed by several research groups, resulting in measurements with improved resolutions. In this research, we investigated an ultrahighresolution optical inspection system for examining fabricated metallic nanostructures using structured illuminations. Images of nanoscale wires and posts reflected in the structured illumination formed by a Liquid-Crystal on Silicon (LCoS) spatial light modulator can be reconstructed to the ultrahighresolution image through post-processing, which shows the improvement of 200 in the lateral image resolution. Comparison with SEM, one of the typical nanostructure imaging instruments, confirms that the investigated system shows high performance and availability as a nanomaterials and nanostructures inspection platform. In particular, since it does not require special environmental conditions such as vacuum and can connect multiple systems into arrays, it saw hope that the optical inspection system can be employed as an inspection equipment for large nanoscale components.

Machine learning and pattern recognition techniques are investigated widely for facial recognition, flaw detection, and microscopy. However, the effectiveness of machine learning in microscopy and sensing depends critically on the quality of the training sets. In nanotechnology applications, it is challenging to obtain large amounts of experimental data for training, testing, and validation because creating appropriate test wafers and making the measurements are costly and time consuming. The data may also be inaccessible because of non-disclosure restrictions. An alternative strategy is to use simulated data for the training set; however, the exact dimensions of the features in the experimental sample may not be known and thus the simulation may not accurately reflect the actual sample. In addition, generating a large library of simulated data for machine learning may be computationally expensive.

To solve the aforementioned limitations of machine learning and challenges of EM modeling, we propose a novel machine learning technique. Principal component analysis (PCA) is a pattern recognition technique that is suitable for image compression and denoising. We transform a few approximate electromagnetic simulation defect images to generate synthetic noisy defect images with trainable parameters such that its principal components can sufficiently capture variance related to the defect features. There are two challenges in implementing this approach. Firstly, the principal components must capture variance related to the defect features. Secondly, the captured variance should contain sufficient feature-related information to distinguish defect and no-defect images. We overcome these challenges by formulating a hypothesis about frame-to-frame varying noise in optical images and use it to generate synthetic images with defect feature dependent noise. In addition, we provide a physical explanation of our technique. It is quite difficult even for image experts to detect a defect, classify its type, and estimate its size from the microscope images because the defect signal is indistinguishable from the background. We therefore developed a novel interpretable machine learning algorithm for automatic detection and classification of defects that uses only a few training samples. We interpret the algorithm as a multi-prong approach to mitigate simulation artifacts and target distinguishing defect features buried in the mutual interference of the background and defect fields. We have utilized the denoising abilities of PCA and overcome the challenges of using principal components for classification and of the limited availability of experimental defect images. We developed a modified gradient descent algorithm for efficient optimization of loss functions.

One downside of the method is the long overall computation time associated with the sliding window step. A second key limitation is that for generalizing this method to other types of images, e.g., phase images, the researcher must add physical insight appropriate to the image type, i.e., the function of the trainable parameters must be decided.

Bottom Note: *This work is partly presented at New Frontiers in Optics, Photonics, Lasers and Communication Systems, May 13, 2019, Tokyo, Japan*