学　位　論　文　内　容　の　要　旨

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A Study on Robust SEM Photometric Stereo Using Two BSE Detectors
（2 つの BSE 検出器を用いたロバスト SEM 照度差ステレオに関する研究）

This thesis presents a novel robust SEM photometric stereo method using two backscattered electron detectors. Robustness is one of the most important factors for practical applications. Although SEM photometric stereo has gained a lot of attention and been extensively studied, the robustness remains a very interesting challenge. Among ill factors, we realize that shadowing and noise problems are almost inherent in SEM photometric stereo. In particular, the shadowing effects generally give rise to significant errors in the reconstructed shapes. The present work is thereby devoted to developing SEM photometric stereo so that it can automatically handle such ill factors.

For dealing with shadowing effects, we introduce a shadowing compensation model though modeling image intensities in both cases of absence and presence of shadowing based mainly on angle distribution of backscattered electrons. This model relates the underlying shadowless image to the observed one by the corresponding detection ratio. The detection ratio has modeled the shadowing generation process by means of shadowing angles, which reflect the amount of occluded backscattered electrons. One advantage of the shadowing compensation model is that it is no need for us to treat the regions with shadowing errors separately from those without such errors, because the shadowless case is special case of shadowing. Therefore, in contrast to some other approaches, the proposed method does not require an image segmentation process to extract shadowing regions, which is substantially difficult to implement automatically. The model has already provided an important cue to eliminate shadowing errors by means of inferring the shadowless images from the observed one if the shadowing angles can be obtained.

With the shadowing compensation model and gradient estimation equation, we formulate the proposed robust shape reconstruction into a constrained optimization problem via a variational approach. The objective functional consists two terms. One is the fidelity term that is to guarantee the gradient of reconstructed shape should be consistent with the gradient data. In particular, the gradient data are evaluated from shadowless images so as to eliminate shadowing errors. In addition, shadowless images are related to the corresponding observed ones through our shadowing compensation model, which forms the constraints. The second term is total variation prior to penalize the roughness of the solution and consequently make our method be robust to noise influence arising in the data term. We adopt an iterative scheme to solve the problem, which performs commutatively between the compensation of image intensities and the modification of the corresponding 3D shape, can effectively provide both an accurate 3D shape and compensated shadowless images after convergence.

We present an extension to the shadowing compensation model in order to improve the model accuracy in the shadowing regions on the general curved surfaces. The extended model removes the

earlier restrictive assumption that the shadowing effects exist only on horizontal surfaces. This model is developed in an analogous way through modeling image intensities in both the absence and presence of shadowing. A numerical solution is proposed to resolve the implicit expressions for double integrals in the model. Compared to the previous shadowing compensation model, the extended model can be more accurate when applied to shadowing regions on surfaces having large inclinations.

Experimental results demonstrate the robustness and effectiveness of our proposed methods. Compared to the traditional methods, reconstructed 3D shapes can achieve higher accuracy. Furthermore, the resulting compensated images provide a potential opportunity for improving the imaging performance of SEM devices.