National Institute of Standards & Technology

Report of Investigation

Reference Material 8091

Scanning Electron Microscope Sharpness Standard

Serial No. 1

This Reference Material (RM) is intended primarily for use in checking the sharpness performance of scanning electron microscopes. It is supplied as a small (2 mm × 2 mm) diced semiconductor chip. This sample is capable of being mounted directly onto a wafer, wafer piece, or specimen stub for insertion into a laboratory or wafer inspection scanning electron microscope (SEM). The chip can also be mounted onto a 'drop-in' wafer type sample holder.[1] RM 8091 is fully compatible with state-of-the-art integrated circuit technology.

Description of RM Unit: Each RM 8091 chip specimen is mounted on gel-pack inside a plastic box that, in turn, is stored inside a foam lined wooden box to protect it from damage and to keep particle contamination to a minimum. The utmost care should be taken in handling and mounting this specimen. One floppy disk containing two image files and one copy each of four published articles are included with each RM 8091 unit. The first file is a well-focused and stigmatic image (focused); the second file is an image with intentionally induced astigmatism in the image (astigmatic). These files are the ones used to develop the following documentation included with this Report of Investigation: Postek, M.T. and Vladar, A.E., "Image Sharpness Measurement in Scanning Electron Microscopy–Part I," SCANNING Vol. 20, 1-9 (1998); Vladar, A.E., Postek, M.T., and Davidson, M.P., "Image Sharpness Measurement in Scanning Electron Microscopy–Part II," SCANNING Vol. 20, 24-34 (1998); Zhang, N.F., Postek, M.T., Larrabee, R.D., Vladar, A.E., Keery, W.J., and Jones, S.N., "Image Sharpness Measurement in Scanning Electron Microscopy–Part III," SCANNING Vol. 21, 246-252 (1999); Vladar, A.E., Postek, M.T., Zhang, N.F., Larrabee, R.D., Jones, S.N., and Hajdaj, R.E., "Reference Material 8091: New Scanning Electron Microscope Sharpness Standard," SPIE Microlithography (2001).

The technical direction for this reference material was provided by M.T. Postek and A.E. Vladar of the NIST Precision Engineering Division. Acknowledgment is also given for the technical assistance provided by N.F. Zhang of the NIST Statistical Engineering Division and R.D. Larrabee, S.N. Jones, and W.J. Keery of the NIST Precision Engineering Division.

The support aspects involved in the issuance of this RM were coordinated through the NIST Standard Reference Materials Program by N.M. Trahey.

Dennis A. Swyt, Chief
Precision Engineering Division

Gaithersburg, MD 20899
Report Issue Date: 05 July 2001

John Rumble, Jr., Acting Chief
Standard Reference Materials Program

[1]Aluminum wafer drop-in type sample holders are available for purchase with this RM in two sizes, 150 mm (6 in) D and 200 mm (8 in) D. The holders are identified as RM 9951 and RM 9952, respectively, and can be ordered with RM 8091

Introduction: All SEMs, whether they are in a laboratory or on the production line, slowly lose performance as the instruments are used. Loss in image quality also means loss in measurement quality. Loss of performance is due to a number of contributing factors, including misalignment, contamination, and increases in source diameter. Identifying a loss in "sharpness" is one way to recognize this performance decrease [1,2]. RM 8091 is intended primarily for use in routinely checking the sharpness performance of SEMs. It is designed to be used in conjunction with the NIST/SPECTEL SEM Monitor Program [3], the NIST Kurtosis Program [4], the University of Tennessee SMART Program [5], or the analytical procedures proposed by Fanget et al. [6].

General Discussion: Fully automated or semi-automated SEMs are now commonly used in the laboratory and in semiconductor production and other forms of manufacturing. Testing and proving that the instrument is performing at a satisfactory level of sharpness is an important aspect of quality control. In industrial applications, such as automated online semiconductor production, users of SEM metrology instruments want to have these instruments function without human intervention for long periods of time. To accomplish that, there needs to be some simple criterion, or indication, of when an SEM needs servicing or other attention. At the present time, no self-testing is incorporated into the majority of these instruments to verify that the instrument is operating at a satisfactory performance level. Therefore, there is a growing realization of the need for the development of a procedure for periodic performance testing.

A degradation of the sharpness of the image of a suitable test object is one of several possible indicators of the need for maintenance. Postek and Vladar [1] published the fundamental philosophy and a procedure based on this sharpness principle. The basic procedure has subsequently been refined into a user-friendly, stand-alone analysis system [2,3]. This concept is based on the objective characterization of the spatial Fourier transform of the SEM image of a test object for this purpose and the development of appropriate analytical algorithms for characterizing sharpness. The main idea, as put forth in those papers, is that an instrument can be objectively tested in an automated manner, and the procedure described therein is one possible solution, and the solution provided as one approach to the problem. Zhang et al. [4,7] presented an alternative statistical measurement approach known as the multivariate kurtosis. Recently, Joy [5] developed SMART routines to measure instrument performance as well. Each of these methods can successfully measure the sharpness of SEM images using an appropriate test sample. RM 8091 was primarily designed for use with the current SEM Monitor program [3]; however, this SRM can be used with the other methods described above.

NOTE on the Sharpness of SEM Images: It is known that the low frequency changes in the video signal contain information about the large features, and the high frequency changes carry information of finer details. When an SEM image has fine details at a given magnification, namely, there are more high frequency changes in it, it is said to be sharper. A procedure based on the Fourier transform technique on SEM images that is capable of high-resolution operation, was proposed by Postek and Vladar [1]. Procedures based on the Fourier transform technique can also be found in References [8-10]. Because SEM images are composed of two-dimensional arrays of data, the two-dimensional Fourier transform generates two-dimensional spatial frequency spectra. Based on the computed spatial frequency spectra of selected SEM images, it can be observed that when one SEM image is visually sharper than a second image, the high spatial frequency components of the first image are larger than that of the second. Zhang et al. [4,7,11] have published an alternative statistical analysis method based on the Fourier transform of SEM images. This method is in the public domain and can be adapted for use by any interested party.

RM 8091: RM 8091 is one type of a class of samples appropriate for testing the sharpness of SEMs. The "ideal" sample for the sharpness evaluation would have diversified size features with exactly known structure in all directions and dimension ranges. This type of sample would be "fractal–like," allowing the user to measure accurately the geometric parameters of the primary electron beam. Because no such sample exists, the only choice is to find or produce artifacts that, at least in the most important magnification ranges, have satisfactory structure.

Beyond the geometry requirement, the sample must yield reasonably noiseless images with good contrast in the upper magnification range. A number of different types of samples have been tested for their applicability to the sharpness technique. The conclusion is that the following characteristics should be present in any sample used for determination of sharpness.

1. The sample must be able to be formed or placed on or into a semiconductor wafer.
2. Because the technique is used in automated wafer fabrication instrumentation, the sample must be able to approximate the product being viewed.
3. The specimen must be solid to avoid any possible particle contamination of the semiconductor wafer during processing. Therefore, latex spheres or zinc oxide powder (common SEM standards) are eliminated from the possibilities.
4. The sample cannot be a source of doping material. Many semiconductor wafer-processing facilities are trying to avoid any use of specimens containing gold because of the fear of unwanted doping of silicon wafers. Therefore, samples, such as gold–on–carbon, are also eliminated as potential samples.

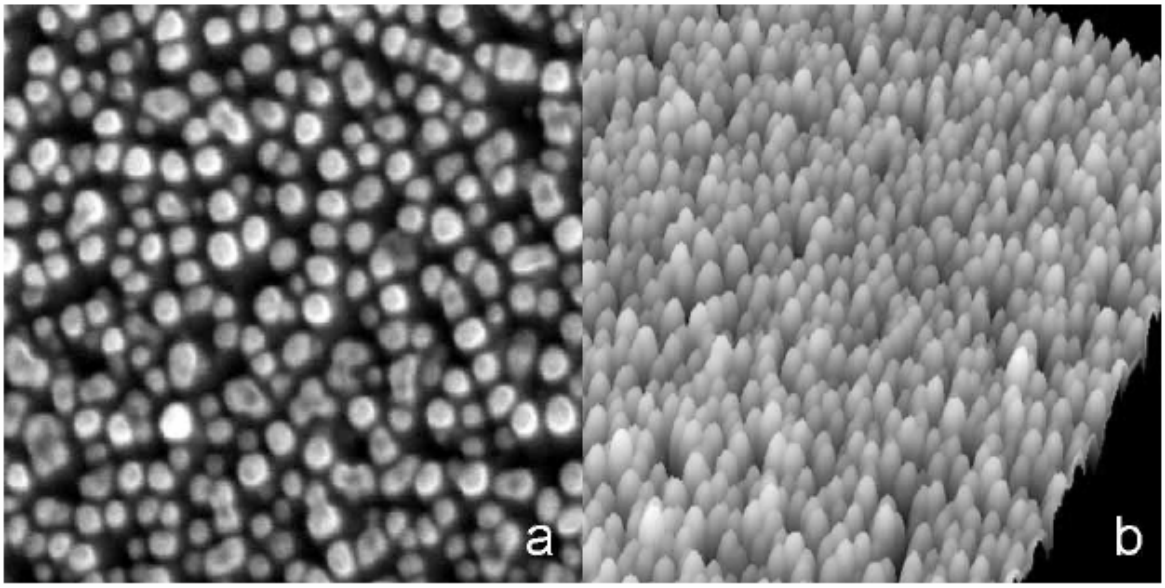

Figure 1. RM 8091 Sample**.** Etched grass; (a) SEM image of a silicon sample, "grass," that is a result of preferential masking during the reactive ion etching**.** (b) An AFM image that illustrates the three-dimensional structure of the grass sample**.** (Field width = 180 nm).

The etching artifact "grass" meets the major characteristics of the evaluation sample as described above and can be used for both laboratory and online instrumentation (Figure 1). A quantity of the grass samples was developed in collaboration with B.L. Newell, formerly of Texas Instruments, Dallas, TX. The grass sample was selected as the sample of choice, although other types of materials were explored by Postek et al. [12] for suitability as a sharpness standard sample. Throughout all the testing, the original targeted grass material was always the specimen demonstrated to be the best for the purpose. The actual production of an SEM specimen with a surface structure containing higher spatial frequencies than the imaging capabilities of good quality, present day SEMs is not trivial. Several different approaches were evaluated and the most promising always remained this etching artifact. Attempts to generate a larger quantity of the grass samples or other similarly suitable substitute were unsuccessful; therefore, the original limited quantity of artifacts were diced into approximately 2 mm × 2 mm size chips for this release as RM 8091. At the magnifications used for analysis of the instrument sharpness, there are over 1 million sites available.

Specimen Contamination: The deposition of contamination on the surface of any specimen in the SEM is a pervasive problem. The surface roughness of RM 8091 makes this standard less susceptible to the effects of contamination. However, as with any SEM inspection, care must be taken to always operate the instrument on a clean area and not dwell too long on any particular area of the RM 8091 surface.

Conclusions: RM 8091 has been developed as a usable artifact for the testing of sharpness of an SEM, whether the instrument is used in the laboratory or the production environment. The surface structure of this material is designed to have greater spatial frequencies than can be imaged by the SEM under evaluation. Therefore, the analysis of the high spatial frequency content of the SEM images of the structure on these images can form the basis of measuring the SEM sharpness capabilities. It has been found convenient and fast to perform this analysis by examination of the two-dimensional Fourier transform of the SEM image. It is anticipated that the use of RM 8091, along with an appropriate imaging analysis, will lead to a simple quantitative criterion to determine when an SEM needs adjustment and/or maintenance. A secondary use of this RM is for the evaluation of the deposition of contamination by the SEM electron beam.

REFERENCES

[1] Postek, M.T. and Vladar, A.E., "SEM Sharpness Evaluation Using the Sharpness Criterion," Proceedings SPIE 2725, pp. 504-514, (1996).

[2] Postek, M.T. and Vladar, A.E., "Image Sharpness Measurement in Scanning Electron Microscopy-Part I," SCANNING **20**, pp. 1-9, (1998).

[3] Vladar, A.E., Postek, M.T., and Davidson, M.P., "Image Sharpness Measurement in Scanning Electron Microscopy-Part II," SCANNING **20**, pp. 24-34, (1998).

[4] Zhang, N.F, Postek, M.T., and R.D. Larrabee, "Image Sharpness Measurement in Scanning Electron Microscopy-Part III. Kurtosis," SCANNING **21**, pp. 256-262, (1999).

[5] Joy, D.C., "SMART – Routines to Measure SEM Resolution and Performance," SCANNING 22(2), pp. 110-111, (2000).

[6] Fanget, G.L., Martin, H.H., and Florin, B., "Survey of Scanning Electron Microscopes Using Quantitative Resolution Evaluation," SPIE Proceedings 3050, pp. 80-92, (1997).

[7] Zhang, N.F., Postek, M.T., Larrabee, R.D., and Vladar, A.E., "Multivariate Kurtosis for Measuring Image Sharpness," Proceedings of the 15th International Workshop on Statistical Modeling: New Trends in Statistical Modeling, pp. 529-532, (2000).

[8] Ong, K.H., Phang, J.C.H., and Thong, J.T.L., "A Robust Focusing and Astigmatism Correction Method for the Scanning Electron Microscope," SCANNING **19**, pp. 553-563, (1998).

[9] Ong, K.H., Phang, J.C.H., and Thong, J.T.L., "A Robust Focusing and Astigmatism Correction Method for the Scanning Electron Microscope - Part III: An Improved Technique," SCANNING **20**, pp. 357-368, (1998).

[10] Dodson, T.A. and Joy, D.C., "Fast Fourier Transform Technique for Measuring SEM Resolution," 12th Proceedings of ICEM, pp. 406-407, (1990).

[11] Zhang, N.F., Postek, M.T., and R.D. Larrabee, "Statistical Measure for the Sharpness of the SEM Image," Proceedings SPIE 3050, pp. 375-387, (1997).

[12] Postek, M.T., Vladar, A.E., Zhang, N.F., and Larrabee, R.D., "Potentials of On-line Scanning Electron Microscope Performance Analysis Using NIST Research Material 2091," Proceedings SPIE 3998, pp. 42-56, (2000).