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P. E. Russell
JEOL U.S.A., Inc.

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SEM Inc., AMF O'Hare (Chicago), IL 60666-0507, U.S.A.

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MICROCHANNEL PLATES AS SPECIALIZED SCANNING ELECTRON MICROSCOPY DETECTORS

P. E. RUSSELL

JEOL U.S.A., INC.,
11 Dearborn Road, Peabody, MA 01960

Phone no.: (617) 535-5900

Abstract

The need for a specialized detector for low beam voltage and low beam current applications has led to the investigation of a microchannel plate detector for SEM. The application requirements are described in detail, with the case of integrated circuit metrology used as an example. The microchannel plate (MCP) detector has proven to meet almost all of the design objectives of a low voltage metrology SEM detector. The symmetry of the detector and the ability to mount it directly to the final pole piece are among the most important features.

KEY WORDS: Detectors, metrology linewidth measurement, microchannel plate, low voltage microscopy

Introduction

While the conventional Everhart-Thornley secondary electron detector has proven to be extremely versatile in scanning electron microscopy (SEM) applications[1,3], there are some applications where development of a specialized detector is warranted. Two such applications are currently receiving active attention due to the needs of the semiconductor industry in the development of VLSI (very large scale integrated circuits). These applications are integrated circuit (IC) metrology[5] or linewidth measurement and quantitive voltage contrast microscopy.[2] Both of these techniques involve low signal levels and place special requirements on the symmetry of the detector and associated electric fields. Thus, at least one of the potential disadvantages of a microchannel plate (MCP) detector is not of concern; that is the inability to handle very high signal levels. The major problem of concern in these applications is the sensitivity of the MCP to contamination.

The IC metrology need is growing as the feature size in IC's begins to reach the one micron or smaller level. At this feature size, traditional optical microscopy based metrology systems cannot provide the required measurement accuracy and precision, primarily because of the wavelength of visible light involved. An SEM based metrology system must retain the non-destructive aspects of the optical counterparts, as well as the ease of operation and reliability. The non-destructive requirement and the fact that most samples (typically photoresist lines on insulating layers) are non-conducting require the use of low beam voltage (500-2000 volts) and low beam currents (0.1 - 5 pA). The topographical nature of features to be measured, and the need for high precision (~100Å) measurement capability in all directions, requires the use of an electron detector which is symmetric around the measurement point and which is very sensitive to low level signals. A microchannel plate detector, such as the one described by Griffiths, et al in 1972[4] easily satisfies these requirements. The detector requirements of the IC metrology application and the results of a MCP detector for this application will now be described in detail.

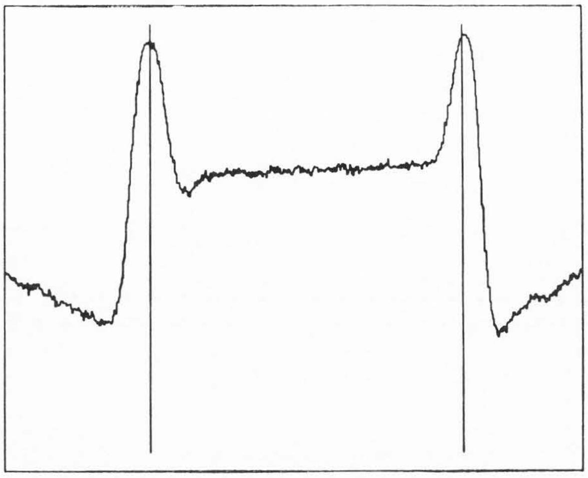

Figure 1. Secondary electron waveform obtained by scanning a 1 keV electron beam across a 1 micron photoresist line; with the measured line pointing directly along the Everhart-Thornley detector axis, and the beam scan direction perpendicular to this axis.

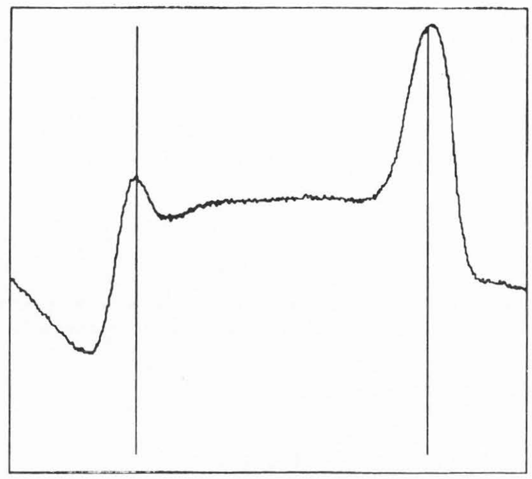

Figure 2. Secondary electron waveform obtained by rotation of the line and scan direction used for Figure 1 by 90°.

Application Requirements

Line width measurement in an SEM is accomplished by scanning the electron beam across the feature of interest and measuring electron emission as a function of beam position. Since the electron beam scan distance can be accurately calibrated, the measured electron emission can be related to features along the measurement direction; in particular to line edges. Secondary electron imaging is known to provide excellent edge detection capabilities and hence the detection of secondary electrons is more desirable than backscattered electron detection alone. (See the paper in this volume by Robinson for a review of electron detectors used in SEM[6]). In using a conventional Everhart-Thornley secondary electron detector, it is found that edge detection capability is strongly affected by the geometry of the detector. If the line to be measured runs directly along the axis of the detector, such that the beam can be scanned perpendicular to the detector axis, both edges of the line can be detected easily. A typical waveform illustrating this is shown in Figure 1. However, if the orientation of the line is rotated by 90°, such that the beam must be scanned along the detector axis, the two line edges are detected very differently, with one edge having substantially reduced signal to noise. A typical waveform illustrating this geometry is shown in Figure 2. Notice the loss of symmetry in going from one orientation to another. This is because the electric field from the detector is not symmetric at the sample; it is actually one-dimensional. There are two major problems with waveforms of the type shown in Figure 2. First, the signal to noise ratio of one edge signal is severely degraded, such that under poor signal conditions edge detection may not be possible. Second, for automated edge detection by simple algorithms, a symmetric waveform (such as that in Figure 1) is less complex and can be handled faster and more reproducibly. Thus, a new detector is required which will provide symmetric waveforms from a line of any orientation in the X-Y sample plane.

The SEM operating conditions required for linewidth measurement included low keV ($\sim$1 keV) and low beam current ($\sim$0.1 to 1 pA). The low keV requirement is imposed by two conditions; the desire to avoid charging by working near the condition of unity electron emission and by the requirement to avoid possible radiation damage which higher keV beams induce. The low beam current requirement is imposed by the sensitivity of specimens to total accumulated dose and by the desire to eliminate charging. Both the low voltage and low current requirements present problems when using a conventional ET detector. The electric field of the ET detector, typically in the range of 100V/cm at the measurement site, causes one-dimensional defocusing of the beam, which is increased in effect as the beam voltage is lowered. The low beam current requirements present signal collection problems. The problem is increased by the need to use very short working distance to obtain small spot size at low keV. This poses geometrical constraints on the ability of the ET collector fields to reach the region between the sample and the pole piece.

Detector Requirements

For the above reasons, a new detector was sought with the following basic specifications:

1) Symmetric collection field so as not to distort a low voltage beam,
2) Short working distance configuration,
3) No requirement for tilting specimen to achieve optimum signal collection,
4) High sensitivity,

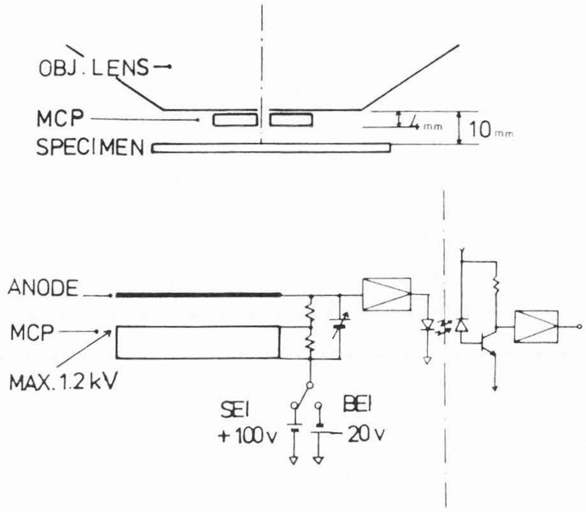

Figure 3. Microchannel plate detector geometry and electrical configuration.

5) Capability to determine angular properties of electron emission, and
6) Ability to detect backscattered electrons.

A microchannel plate detector, similar to that described by Griffiths et al[4], has been successfully implemented to meet these objectives. The geometry of the microchannel plate detector is shown in Figure 3.

The detector assembly is mounted directly on the final lens assembly and requires only 4mm of space below the pole piece. The working distance of 10mm has been chosen in this example, due to other design considerations. The detector itself is disk shaped with a shielded center hole for the primary electron beam. A high voltage across the MCP provides the electron multiplication; this voltage is 1000-1200 volts. The front surface of the detector is biased at +100V for enhanced collection of secondary electrons and at -20V for suppression of secondaries; i.e., for backscattered electron imaging. The entire assembly is electrically isolated from the SEM by use of optical decoupling. The electrical configuration is shown schematically in the lower portion of Figure 3. The actual signal measured is the current collected by the MCP anode plate.

Results

The low beam voltage performance of the MCP system is illustrated in Figures 4 and 5.

Figure 4 shows the detector output current as a function of extraction (or bias) voltage applied. The extraction voltage is seen to strongly increase the overall gain as the voltage is increased from 0 to 100 volts. Above 100 volts the increase is small. Data is shown for 0.5, 1.0 and 3.0 keV beams, all showing similar effects. Based on this data 100 volts was chosen as the optimum voltage for secondary electron collection. The MCP output current

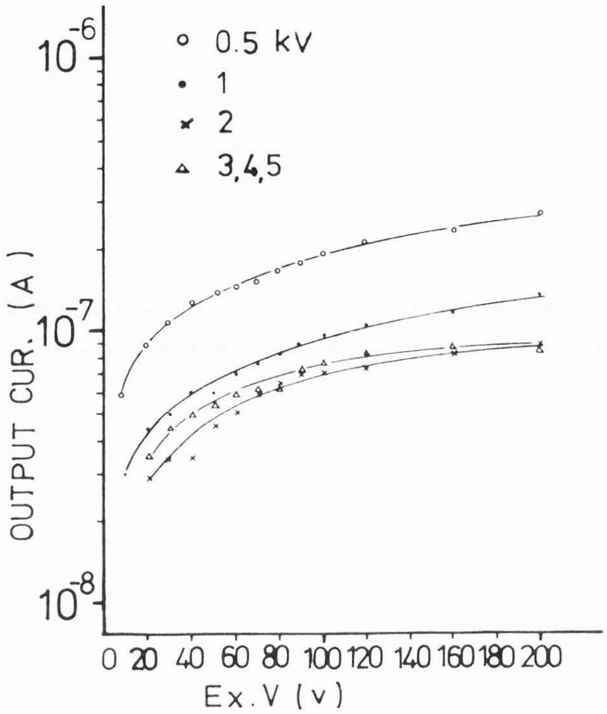

Figure 4. MCP detector output current versus extraction voltage for 0.05, 1, 2 and 3.0 keV primary beam with 1 pA beam current.

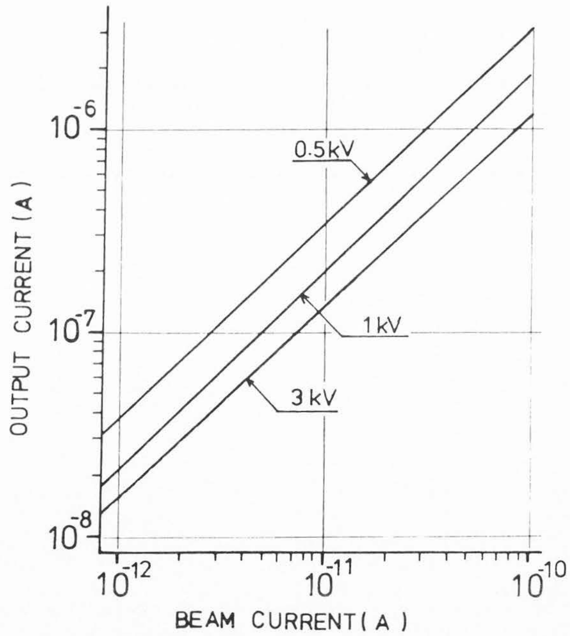

Figure 5. MCP detector output current versus primary beam current for 0.5, 1.0 and 3.0 keV beam voltage. Extraction voltage is 100V.

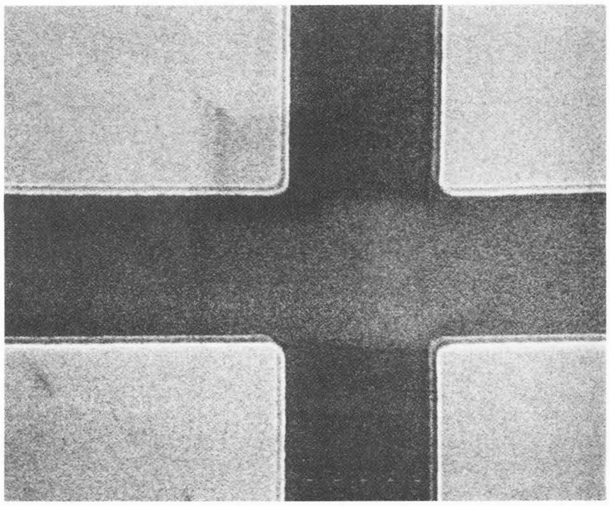

Figure 6. Micrograph of cross pattern (2 micron linewidth) obtained using MCP detector; 1 keV and 1 pA beam conditions.

versus primary beam current is shown in Figure 5, again for 0.5, 1.0 and 3.0 keV beams. The gain is shown to be linear over the beam current range of 10^{-10} to 10^{-12}A. The output current is higher for the low keV beams due to the increase in secondary electron emission. Overall, the MCP detector system is shown to produce acceptable signal levels for the low current, low voltage applications described above.

An image obtained using the MCP detector is shown in figure 6. A 2 micron polysilicon line is shown imaged with 1 keV and 1 pA. All edges are shown to be easily detected. Waveforms obtained from any orientation line result in symmetry and signal to noise such as that shown in Figure 1.

Conclusion

A summary of the attractive features of the microchannel plate as a specialized IC metrology detector is as follows:

- symmetric geometry which allows measurement of features in any orientation
- high sensitivity
- ability to mount directly to lower pole piece, thus allowing very short working distances to be used while maintaining high signal levels
- causes no beam position shift when changing keV (due to symmetry of electric fields involved)

The MCP detector system described above has been implemented on a prototype instrument for approximately 1 year. The system has achieved all design goals and has shown very good stability and reliability. Field installation of several of the detectors in dedicated IC metrology SEM's has been completed. Current investigations include the use of the MCP detector in other applications, the use of a segmented anode plate, and the effects of vacuum level and contamination on detector performance and reliability.

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Discussion with Reviewers

J.B. Warren: Solid state BSE detectors mounted on the pole piece and specimen current imaging would also seem to meet the criteria listed in the paper for line width measurement. Is the signal-to-noise ratio of the MCP detector superior to these methods for the current and voltage regime described?

Author: It is true that solid state backscattered electron detectors and specimen current imaging in principle provide axially symmetric imaging. However, since edge detection is the major objective of the work described in this paper, and since low beam energies (typically 0.7 keV to 2.0 keV) are required, solid state backscattered electron detectors are not suitable. Also, since the specimens are non-conducting, and the beam voltage is such that absorbed current is essentially zero, absorbed current imaging is not suitable.