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# Is SEM Noise Gaussian?

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Noise in the scanning electron microscope (SEM) is defined as being the random fluctuations which occur in the signal observed from a particular pixel in the image even under conditions where the incident beam, the sample, and the recording conditions are kept constant. This noise is then the result of the fact that electron production from the gun, and electron interactions with the specimen are statistical in nature and consequently are different for every individual electron. It is usual to assume that the noise satisfies Gaussian statistics. Thus if the mean number of electrons emitted from a given pixel is N, then the standard deviation of the signal, and hence the noise component, is $N^{1/2}$ . Since noise significantly affects the predicted performance of an electron-beam tool, especially in applications such as defect detection during semiconductor fabrication, it is necessary to test this assumption. In addition there is increasing interest in simulating SEM images for various purposes, and the need to incorporate realistic noise in such cases also raises the question as to its exact nature.

The experiment consists of taking defocused images of clean polished Si wafer using SE under various conditions of beam current (1pA, 15pA, 48pA, 0.34nA etc.) and dwell times using digital collection. The mean number of secondary electrons per pixel for 1pA ranges from 1 electron to 416 electrons approximately for different dwell times. The signal level is adjusted so as to place the average signal level approximately in the center of the dynamic range of the system. Micrographs were then analyzed in SCION IMAGE to generate a histogram of the intensity distribution. The centroid of this represents the mean signal level ($\mu$), the standard deviation ($\sigma$) is a measure of the noise, hence a signal to noise ratio (SNR) can be deduced. The noise was further analyzed using EXCEL spreadsheets. For each experimental condition an attempt was made to fit first a Gaussian, and then a Poisson distribution to the histogram. If x is the number of events then,

$$\text{Gaussian distribution } f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp[-1/2[(x-\mu)/\sigma]^2]$$

$$\text{Poisson distribution } f(x) = \frac{\mu^x}{x!} e^{-\mu}$$

The deviation between Gaussian, or Poisson, behavior can then be observed and quantified. Typical results at 1pA for different mean electrons per pixel are shown in figures 1, 2, 3 and 4. It should be noted that for example in figure 2, the mean number of SE i.e 3.2 corresponds to mean signal level of 98. It is evident that, as anticipated, the distribution varies with mean number of SE emitted per pixel. The distribution becomes accurately Gaussian for any value of $\mu$ (SE per pixel) larger than about 10. However for lower values of $\mu$ the experimental data does not tend towards a Poisson distribution, but becomes flattened. This may be evidence that the SE emission is not entirely random but may display some local time correlation.

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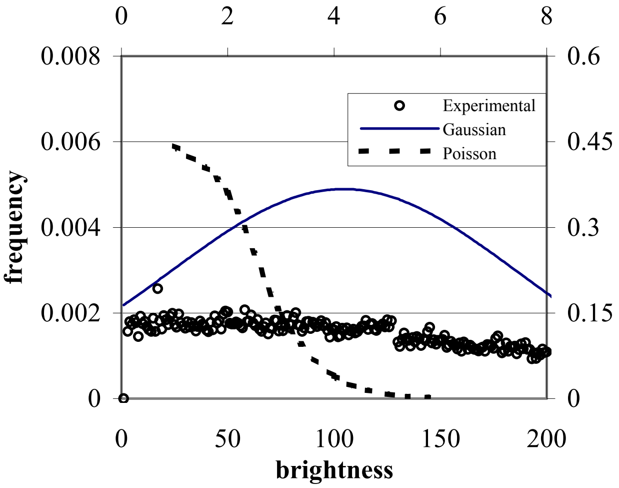

**Fig.1 : Beam current = 1pA, mean SE = 0.8**

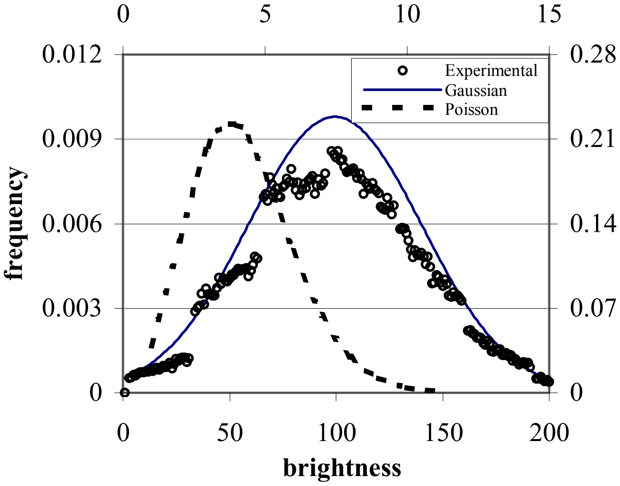

**Fig.2 : Beam current = 1pA, mean SE= 3.2**

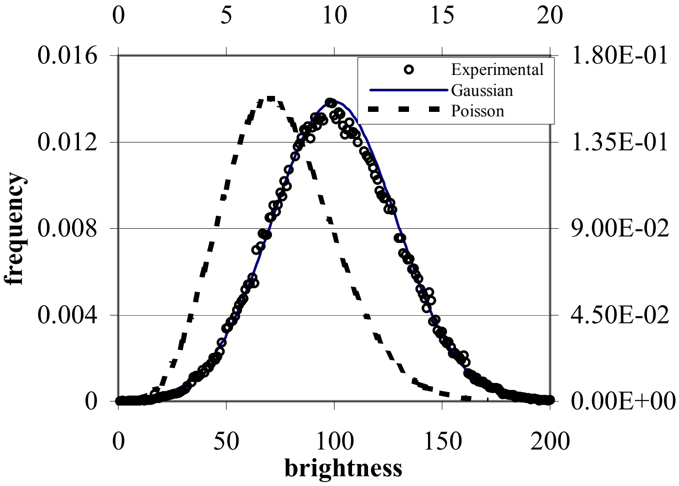

**Fig.3 : Beam current = 1pA, mean SE = 6.5**

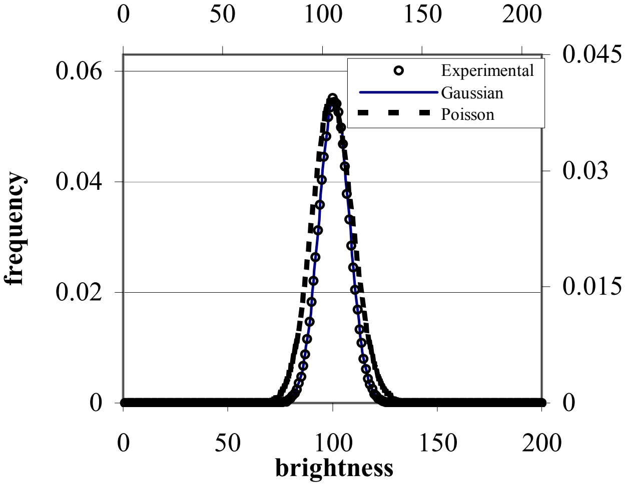

**Fig.4 : Beam current = 1pA, mean SE = 104**