Determining the range and intensity of backscattered electrons from the substrate density and atomic number

D. A. Czaplewski, L. E. Ocola, and Martin V. Holt

Center for Nanoscale Materials, Argonne National Laboratory, Argonne, IL 60439

dczaplewski@anl.gov

In electron beam lithography, creating high-fidelity patterns is essential for the realization of mechanical, electrical, and optical devices with functionalities unique to the nano-scale. E-beam lithography relies on the direct write dose and a precise understanding of the backscattered dose contribution, determined by the geometrical distribution, β, and intensity, η, of backscattered electrons from the substrate[1]. However, predictive models for these parameters do not exist for general substrates. Here, we report on the development of universal curves to predict the range and the intensity of backscattered electrons from the density and atomic number of a solid material, respectively, using a new experimental method called Hybrid Amplified Backscatter Resist Exposure (HABRE). This method combines two key elements, (i) Hybridization of direct write dose and backscatter dose and (ii) Amplification of backscatter dose contribution using a self-reinforcing pattern geometry. Using electron beam lithography, we control the number and position of electrons incident on the material surface. We use an electron sensitive polymer to measure the dose provided by backscattered electrons to a nano-scale volume on the surface of the material at various distances from the electron source. From data collected using the HABRE method on several homogenous materials, we present an analytical relationship to predict the range of backscattered electrons as a function of the density of the material (Fig. 1). This relationship achieves good agreement with a simple model using a single scattering event and an electron transmission function derived from available Monte Carlo simulations[2]. We also present an analytical relationship to predict the absolute intensity of backscattered electrons as a function of the atomic number of the material (Fig. 2).

[1] Wuest, R. *et al.* An efficient proximity effect correction method for electron-beam patterning of photonic-crystal devices. *Microelectronic Eng.* **67-68** 182 (2003)

[2] Lazurik, V. and Tabata, T. Electron-Material Interaction Database Version 1.4 http://www3.ocn.ne.jp/~tttabata/emid/Welcome.htm (2001)

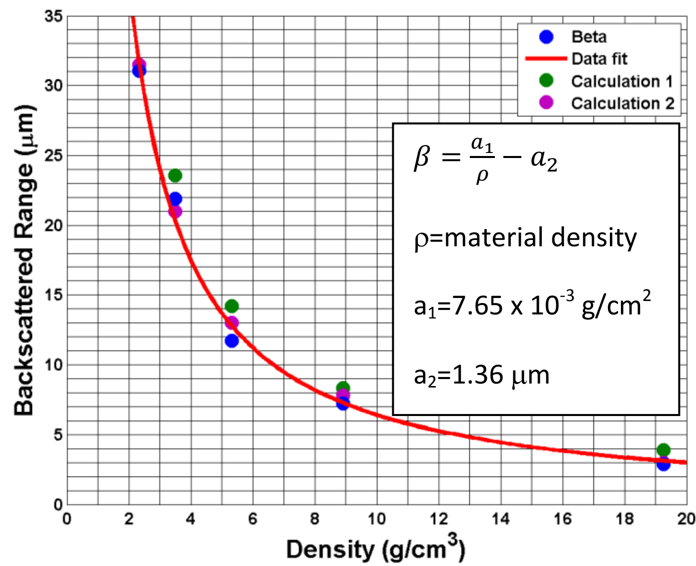

Figure 1 Backscatter range for the 5 measured materials as an inverse function of material density. Included are calculations of backscatter range from 2 Monte Carlo simulations, using electron transmission data from an external source (Calculation 1) and an internal code (Calculation 2). Uncertainties of the data are encapsulated in the size of the data points.

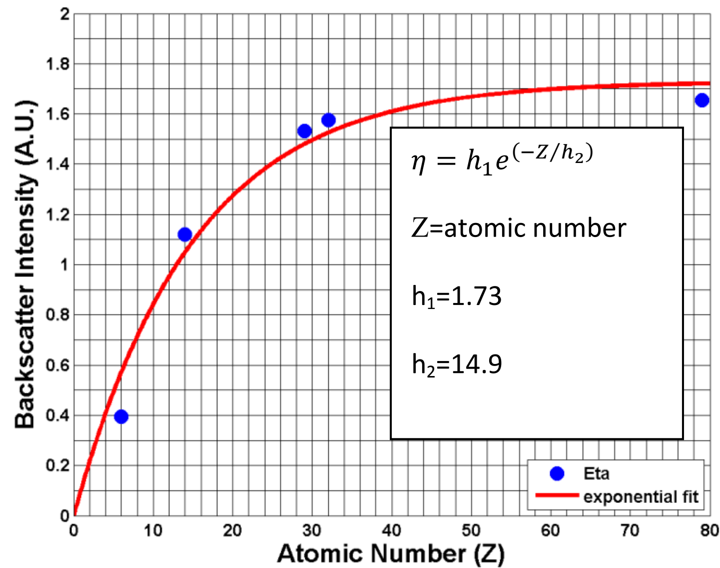

Figure 2 Values of η for the materials used in this experiment plotted as a function of the atomic number of the material. This relationship is represented by a saturating exponential function which can be used to predict values of η for different materials that were not measured here. Uncertainties of the data are encapsulated in the size of the data points.

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