Online Database of Experimental Electron Scattering Properties for SEM Users

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BIOGRAPHY

Eli Napchan received his BSc in mechanical engineering and his MSc in materials science from the Technion, Israel Institute of Technology. His PhD thesis work on heterojunctions of Si and CdTe at Imperial College London, under the supervision of Prof. David Holt, used electron trajectory simulations for the understanding of junction behaviour in the SEM. The experimental scattering parameters described in this article were used to test the simulation programs.

ABSTRACT

In recent years a large database has been collected from many experimental results on various aspects of electron-solid interactions, such as stopping powers, backscattered and secondary electron emission yields, the data format being a series of measurements for a specific parameter as a function of beam voltage. These data have provided useful observations on the variation of measured parameters as a function of beam voltage, and also of the spread in the measured values by different authors. A further use of the data is in X-ray microanalysis correction procedures, and for testing electron-matter simulation programs. This paper describes an online system created to display the experimental data, and to allow the addition of further experimental results to them. The system is openly available, and can be used by researchers interested in the results of interaction of an electron beam with a specimen.

KEYWORDS

scanning electron microscopy, X-ray microanalysis, electron scattering, backscattering coefficient, secondary yield, stopping power, electron trajectory simulation

ACKNOWLEDGEMENTS

I thank David Joy for his database and for permission to process and display its data.

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Microscopy and Analysis 21(4):15-17(UK),2007

INTRODUCTION

Among the most commonly available signals in the scanning electron microscope (SEM) is the number of electrons emitted from the specimen under observation. These vary in energy from a few eV to almost the full extent of the primary electrons (PE) energy, and are usually divided into two types: secondary electrons (SE) are considered those with energies below 50 eV; while backscattered electrons (BSE) are those electrons with energies greater than this value. Although the energy value seems arbitrary, the resulting signals show additional differences: backscattered are usually electrons from the primary beam with well-defined angular distributions.

A more practical difference is that of the depth, and in general the specimen volume, from which each type of electron is emitted. Secondary electrons, due to their low energy and consequently their small inelastic mean free path are emitted from up to about 15 nanometres deep, and from an area close to the beam impact point. Backscattered electrons are emitted from most of the PE interaction volume, and therefore have generally a poorer geometric resolution. The difference in the interaction volumes is the main reason for the use of secondary electrons for imaging purposes, although a small fraction of these is linked to a the BE interaction volume by being generated by the BE on their exit from the specimen surface.

From the experimental point of view, the detection of each type of emitted electron is usually done with a different detector, and the measured signal is usually considered to be either SE or BSE. Values of the SE and BSE yields are given as absolute numbers, relative to one incident PE. It is clear that BSE values are lower than one, while those for SE usually follow a bell-shaped curve (as a function of beam accelerating voltage), the maximum of which is usually higher than one.

In recent years a large number of experimental electron scattering results have been collected in a single document/database (as Microsoft Word documents) from many experimental results and became known as the Joy's database file [1,2]. Measured parameters include stopping powers, backscattered and secondary electrons, for a large number of substrate materials, with the general format of the data being a series of measurements for a specific parameter as a function of beam voltage.

These data have provided useful observations on the variation of measured parameters as a function of beam voltage, and also of the spread in values measured for the same parameter by different authors. These data are used in X-ray microanalysis correction procedures, widely available in routine scanning electron microscope work.

Another application for this collection of experimental values is their comparison against the output from Monte Carlo simulation programs, as backscattering and secondary electron coefficients can be easily calculated. In this way, one aspect of the 'correctness' of the simulation can be accessed, and the usefulness of the application of various algorithms in the calculations can be compared.

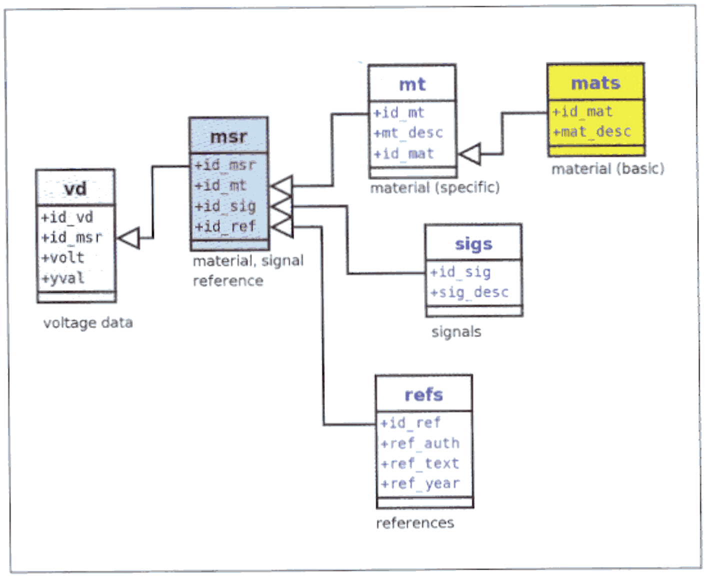

Figure 1: Relational structure of the tables in the system, showing the various columns in each table.

METHODS AND RESULTS

The database was originally created as a text document in Word format, with lists of data for the various parameters from all the references available. This format did not allow for easy visualization and comparison of the various datasets.

The first implementation of the on-line data display used all the data in the database to create static pages for each material and for each type of signal (see the system in [3]). The text parsing program *perl* was used to separate the various datasets, and the plotting script *gnuplot* was used to plot the graphs for each page.

Although the method described served its purpose of data display, making the data web accessible and providing a wider and easier access to it, it had a few drawbacks. Because the pages were static, with each change in the database, for example when new datasets were entered, it was necessary to process all datasets again (as it was required to process the data automatically). Another disadvantage was that due to the fact that the graphs already existed, and so it was not possible to change them, for example, to look at data in a particular range.

The goals of the current work were intended to continue with the functions in the previous system, but to make the new system more manageable and flexible. For example, to allow adding additional datasets, allow general comments about the available data, and have graphs that can be modified.

To achieve these aims, the data were organized in database tables using a relational database model, starting from the current text version of the database [2]. This allows viewing the data according to the different objects involved (materials available, measured parameters and references), and also provides a web interface for adding additional data. This new database [5] is now available online.

The various tables in the system and their relationships are given in Figure 1. Table *mats* contains the basic materials, while its linked table *mt* contains variants of the basic material. For example, silicon appears as a basic material, with the variants of crystalline and amorphous appearing in table *mt*. The table *msr* is the dataset repository, while the actual data for the dataset are contained in table *vd*.

The system is built using only open-source software: *php* as a scripting language, *mysql* as the relational database system, and *jp-graph*, a specialized library for *php*, as the module which creates the graphic plots. The complete system is hosted by a server which in addition to this database contains the author's electron trajectory simulation programs. The data, as well as the source code, are in the public domain, and available to any interested party.

The user interaction with the system (GUI) is through one of three separate screens, which can be accessed from each other. Their specific functions are: to view the contents of the database tables; to add datasets to the system; and to graph existing data.

Figure 2 shows the form for viewing the contents of the system, as it is stored in the individual tables. On pressing the *View* button, the data in the selected table are shown at the lower part of the screen. Figure 3 shows the form for adding data to the system. The action of *Submit* sends the completed data to the system maintainer, which after checking, are inserted manually into the database tables.

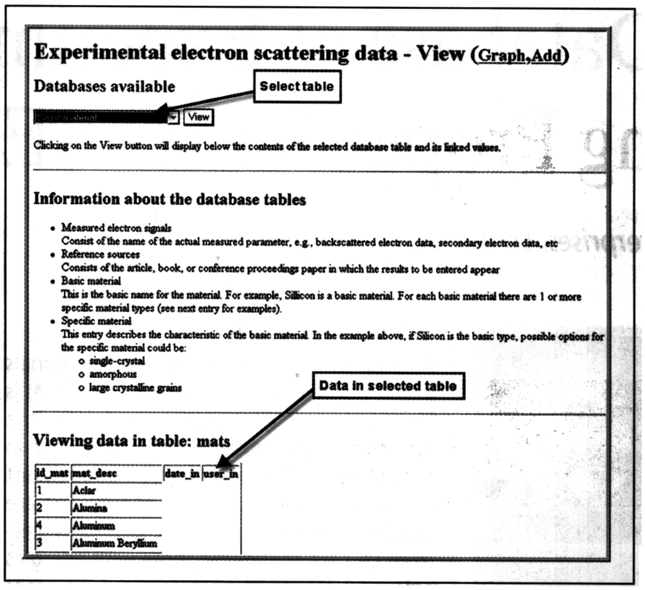

Figure 2:
Form for viewing the contents of the database tables.

Figure 4 shows the form used for generating graphs from the database. Available signals consist of either SE yield, BSE yield, or stopping power; once this is selected, the list box on the right is updated with the available materials. The contents of this list box are the material types from the '*mt*' table, with the basic material name appended to it. In this list box, it is possible to select any number of materials to be plotted on the same graph.

Figure 5 shows the data display when SE yield for gold is selected, in the form of a web page created on-the-fly by the program. By default all datasets for the relevant conditions are plotted, the axis extents auto-adjusting to fit. Each dataset is plotted with a different colour, and a legend on the graph links the line plot with the reference to its source, which appears at the bottom of the page.

Gold is one of the most common materials used (and thus measured) in the semiconductor industry, with as much as 12 different measurements of its SE yield as a function of beam voltage. It is also one of the more 'stable' materials, with a stable surface, both chemically and topographically. It can be seen from Figure 5 that although most measurements of the SE yield of gold show similar trends with decreasing beam voltage, there is a significant variation in the measured values.

Figure 6 shows the BSE coefficient values for both gold and silicon, for beam voltages up to 100 kV, all datasets available for both materials being plotted. For each material, all datasets show the same trend, but this trend is opposite for each material. While the BSE coefficient for gold (top part of the graph) decreases with decreasing beam voltage, for silicon the opposite type of behaviour is observed: the BSE seems to increase with decreasing beam voltage in the range between a few kV to about 30 kV.

DISCUSSION & CONCLUSIONS

Despite the large amount of experimental data on the electron scattering, significant gaps exist both in relation to specimen mate-

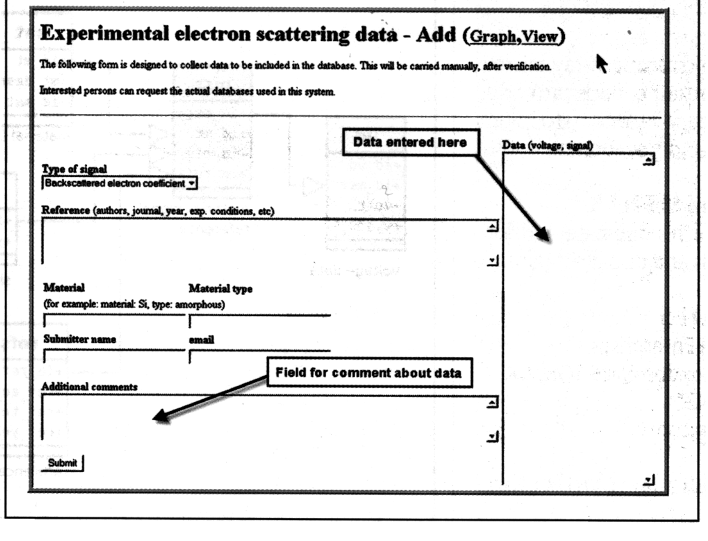

Figure 3:
Form for adding experimental data to the database. Data are added manually, after checking.

rials and beam accelerating voltages for which data are not available. This is particularly true for the low accelerating voltages that became more popular due to equipment developments over the last few years, and for new combinations of materials such as compound semiconductors (for example, the database does not have values for gallium nitride). Even for materials that are widely investigated at 'standard' operating conditions, the literature values from different authors may vary by as much as 50%.

In addition to the non-existence of data for important materials under all or certain beam accelerating voltages, problems can be seen also in the existing data. The SE yield depends not only on the beam accelerating voltage, but also on the sample surface preparation or condition prior to the investigation. For materials such as those used in particle accelerators, it has been shown [4] that the surface condition can affect the values of the SE yield by as much as 50%; for PE accelerating voltages below 3 kV, the highest change being usually at the maximum of the SE yield curve. This makes it necessary to better qualify the experimental setup in which data are obtained, for example by specifying vacuum conditions, detector setup, and perhaps most important, specimen surface information. Existing data should be further qualified by comments about specimen preparation and experimental conditions.

Despite the large variation present in the experimental data, by providing a system with features described in this article, it is hoped that the database becomes a real-time repository for this type of information, including the most recently available data, both experimental and theoretical. It is also to be hoped that this will lead to better measurements and understanding of the variations of the various parameters, and to a more accurate evaluation of microscopy simulation programs. An example of an interesting material behaviour that has been observed using the current system has been shown in Figure 6, where the overall trend of the BSE coefficient is different for two commonly used materials.

Using the database system described in this article, electron scattering data are plotted in real-time for any number of concurrent users, after selection from the available experimental conditions parameters. New data can be easily added to the system, and comments made (to the authors) about existing data. These additional data are checked before being included in the database and in the online system.

Considering the above points, future work to be carried out on the system will include:

1. Additional processing of existing data: selection of data sets for display, plotting data in a logarithmic scale, adding notes to datasets with sample and experiment details.

2. Adding analytical calculations for SE and BSE, to be used for comparisons with the experimental data. Various theories exist for the empirical calculation of scattering parameters, such as the model for SE yield for carbon and low atomic number materials given in [6], which would be of value to have online for comparison with the experimentally observed data.

3. Adding other calculated data, such as Monte Carlo simulations results, for comparison with other sources.

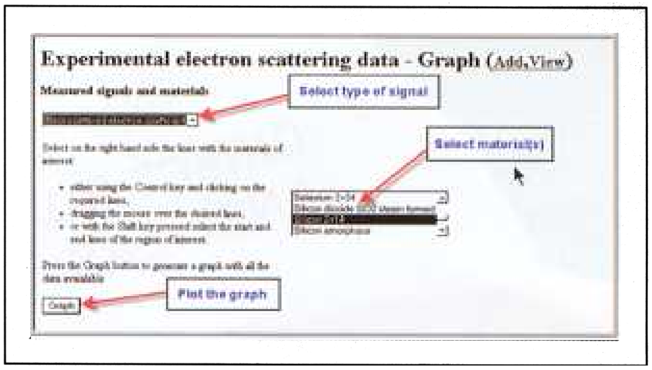

Figure 4:
Form for selecting what data to graph: the type of signal and the material(s) to be displayed.

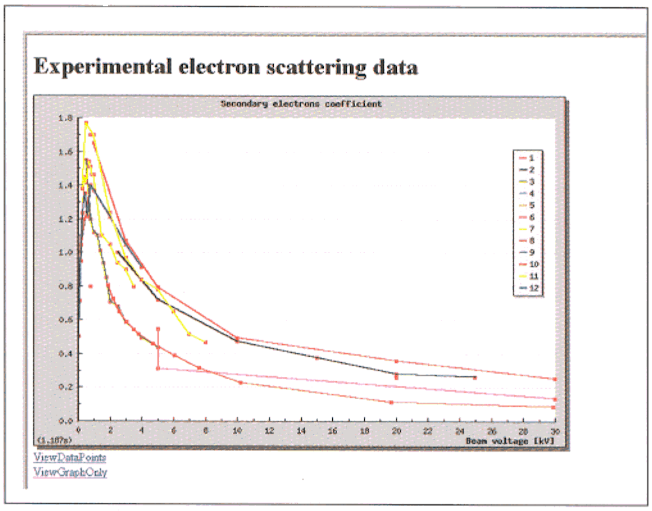

Figure 5:
Secondary electron yield data for gold, including all datasets and their sources (references).

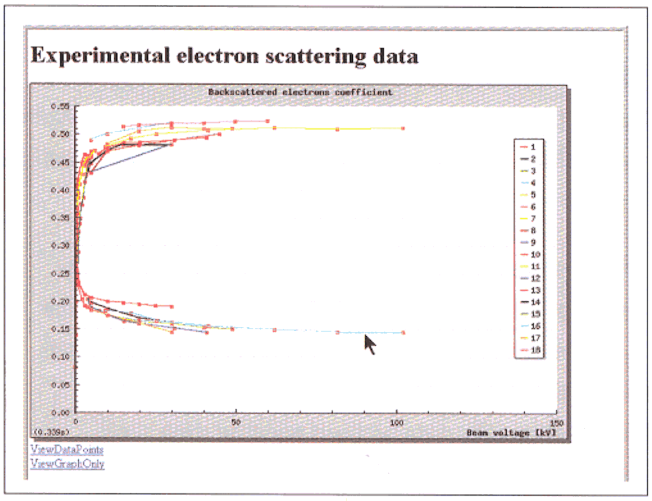

Figure 6:
Graph of backscattered electron coefficients for gold and silicon.

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