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Secondary-Electron Signal Levels of Self-Assembled Monolayers for Spatial-Phase-Locked Electron-Beam Lithography

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A long-standing problem in scanning-electron-beam lithography (SEBL) is beam-placement error, which distorts patterns within individual fields, between fields, and over long distances. Such error originates from a multitude of disturbances [1]. Spatial-phase-locked electron-beam lithography (SPLEBL) addresses this problem by continuously tracking and correcting the position of an electron beam using the signal from an electron-transparent fiducial grid placed on top of the resist. Placement accuracy of $\sigma = 1.3$ nm has been demonstrated at 10 keV using the secondary-electron (SE) signal from an 8 nm-thick aluminum (Al) fiducial grid on an 8 nm-thick SiOx interlayer [2]. Combining SPLEBL with scanning-electron-beam microcolumns could potentially provide a low-cost lithography tool with high resolution and high pattern-placement accuracy. To achieve electron transparency in the 1 to 5 keV range, where microcolumns operate, the fiducial grid must be very thin and composed of a low-atomic-number material. The grid material must also have high SE yield (SEY) and high contrast to achieve high signal-to-noise ratio (SNR), as required for accurate beam-position estimation. Self-assembled monolayers (SAMs) have been proposed for the fiducial grid. A SAM grid of amino-propyl-triethoxy-silane (APTES) on 5 nm-thick aluminum provides the highest SNR reported to date [3] for a practical low-beam-energy grid.

In this article, two new SAMs are investigated: bis[3-(triethoxysilyl)propyl]tetrasulfide ("tetrasulfide") and (4-chlorophenyl)triethoxysilane ("chlorobenzene"), and compared with APTES. Figure 1 shows measurements in an SEM of the relative secondary-electron yields of the SAMs, as well as evaporated films of Al and Ti, 100 nm thick on Si. A metal thickness larger than the SE escape depth was used to ensure that the measured signal levels originate solely from the SAMs or the metal, with no contribution from an underlying substrate. The metal-coated samples were immersed in SAM precursor solutions for 24 hours, rinsed with hexane to remove excess precursors, and blown dry with nitrogen. Data were collected using a Faraday cup, a reference material, and a test material. In the graph the Faraday-cup signal provides a zero-level SEY reference; a signal level of 1 corresponds to that of bare silicon with native oxide. The SEYs for aluminum and titanium are normalized to silicon, and silicon provides a reference level for the SAM test materials. As shown in Fig. 1, tetrasulfide-on-titanium provides the highest signal level, substantially exceeding that of the previously reported APTES-on-aluminum.

For a grid signal, an important metric is the contrast between SAM-on-metal and bare metal. Figure 2 plots contrast between tetrasulfide-on-titanium and bare titanium as well as APTES-on-aluminum and bare aluminum, and cross-combinations thereof. Tetrasulfide-based SAMs are especially promising grid materials. Careful control of the chemical functionality of the SAM may yield a fiducial grid with higher SNR for low-beam-energy SPLEBL.

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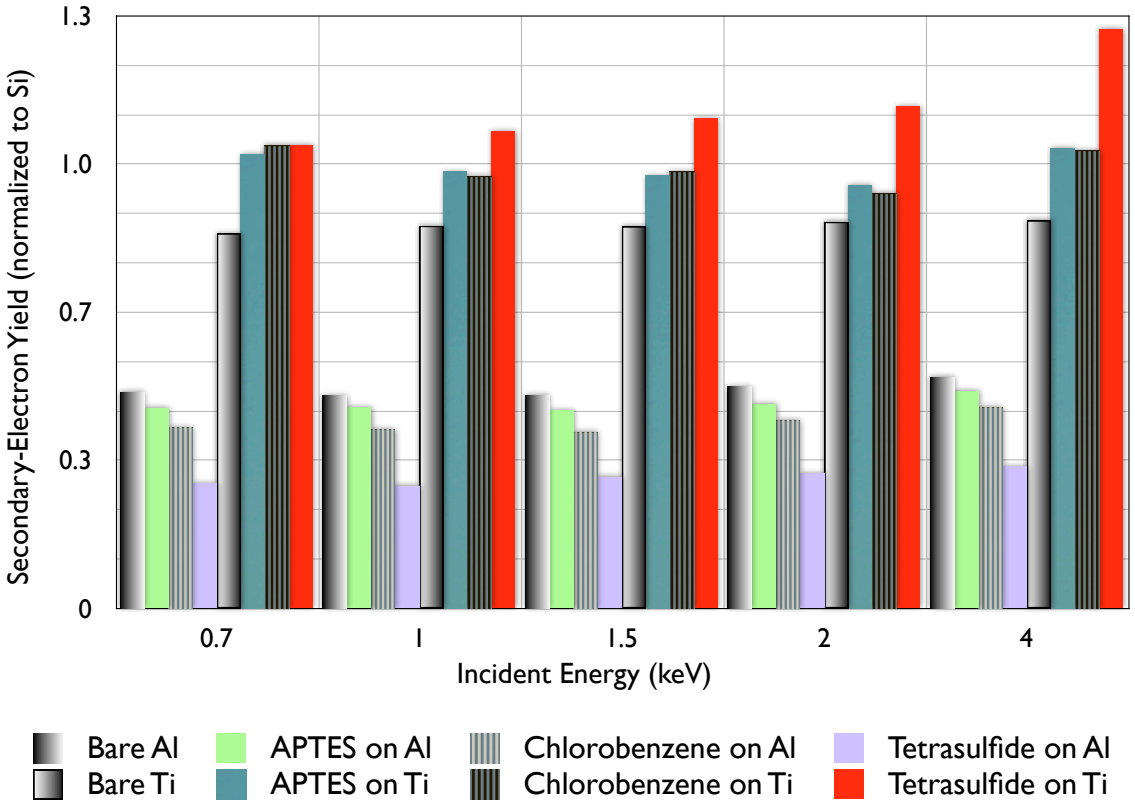


Figure 1. Plot of measured levels of the secondary-electron signals from SAMs on titanium (Ti) and aluminum (Al). All data were normalized with respect to the signal level from silicon with a native oxide. The signal level is greatest for tetrasulfide-on-titanium.

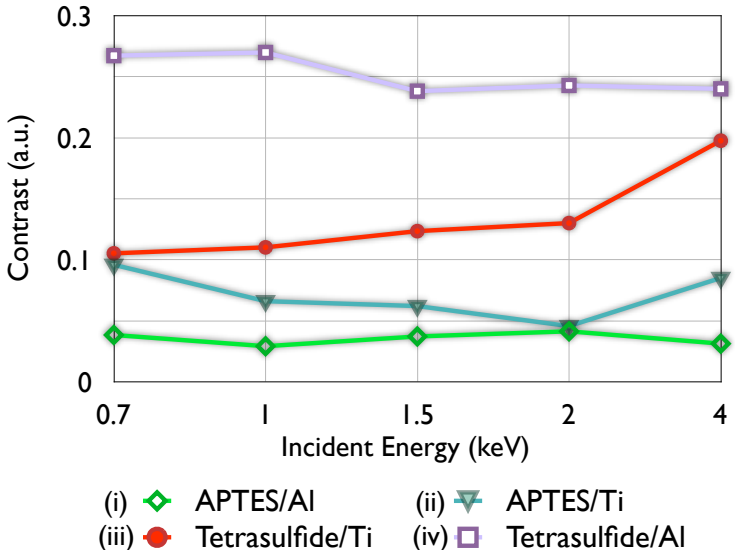


Figure 2. Plots of signal contrast ((max-min)/(max+min)) between (i) APTES-on-aluminum and bare aluminum, (ii) APTES-on-titanium and bare titanium, (iii) tetrasulfide-on-titanium and bare titanium, and (iv) tetrasulfide-on-aluminum and bare aluminum. Tetrasulfide-on-aluminum provides the best contrast, but tetrasulfide-on-titanium offers good contrast and the highest SE yield, especially at higher beam energies. Both tetrasulfide SAMs-on-metal are preferable to APTES.