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Mechanism of Si Field Evaporation

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3-D imaging microscopy techniques are becoming increasingly important to the Si nano-device community. To evaluate the effectiveness of atom probe tomography as a characterization technique for Si nano-devices, detailed field evaporation studies of high (10 ohm-cm) and low (.001 ohm-cm) resistivity <100> Si were performed. Si field evaporation rates were quantified by monitoring the time needed to evaporate 10,000 Si ions from a Si microtip at a given temperature and voltage. These data were collected in DC mode and pulsed mode (pulse fraction = 10% of DC voltage). No imaging gases were utilized and the pressure of the analysis chamber was maintained at 10^{-8} Pa. The array of sharpened Si microtips (100 microns tall, 10 micron diameter base, ~50 nm diameter tip, 450 micron tip spacing) were formed on a Si coupon, and the microtips were sharpened simultaneously in an hydrofluoric-nitric-acetic etch solution, resulting in near-identical tip shapes throughout the array [1]. One million ions were field evaporated from each tip to create an appropriate tip shape.

Results from both pulsed and DC experiments are shown in Figs. 1 and 2. Fig. 3 displays the normalized field required to evaporate 10,000 Si ions in a fixed period of time as a function of temperature. Results were similar for the high and low resistivity Si. Above 110K, Si field evaporation follows accepted models [2]. Below 110K, however, field evaporation of both high and low resistivity Si share a similar independence from specimen temperature. This contrasts with other materials and suggests that below 110K an athermal evaporation mechanism dominates Si field evaporation.

These figures also indicate that two distinct evaporation modes exist. The first mode, termed the H-assisted mode, has small amounts (~1%) of H present in the mass spectrum. This mode prevails at lower evaporation fields or lower temperatures, which is also where a lower evaporation rate is expected. The influence of H on field evaporation is a well-studied phenomenon [2]: hydrogen adsorption and subsequent evaporation from the specimen is expected at low fields/temperatures. The second mode, termed the Si-evaporation mode, prevails at higher voltages/temperatures where H adsorption is precluded. At 110K and above, the H-assisted mode and the Si-evaporation mode form separate linear curves, Fig. 4, with different slopes of field vs. temperature. The H-assisted mode has a slope of -0.01 and the Si-evaporation mode has a slope of -0.0063. An extrapolated line indicates that both modes share a similar y-intercept of ~ 1.55. The slope of these lines relates to the pre-exponential evaporation rate constant and the y-intercept relates to the zero-field activation energy for evaporation [2]. In these experiments, the presence of H reduces the pre-exponential evaporation rate constant above 110K. It does not, however, alter the intrinsic zero-field energy in this temperature regime. Below 110K the data indicate that the presence of H reduces the effective activation energy but that the pre-exponential evaporation rate remains approximately constant.

In the current work, two interesting phenomena relating to Si field evaporation have been observed. These observations have important implications for analyzing Si-based structures in the atom probe.

[1] K. Thompson, D. J. Larson, R. M. Ulfig, *Microsc. and Micronal.*, this volume.
[2] M.K. Miller, A. Cerezo, M.H. Hetherington, G.D.W. Smith, Atom Probe Field Ion Microscopy, Oxford University Press, 1996.

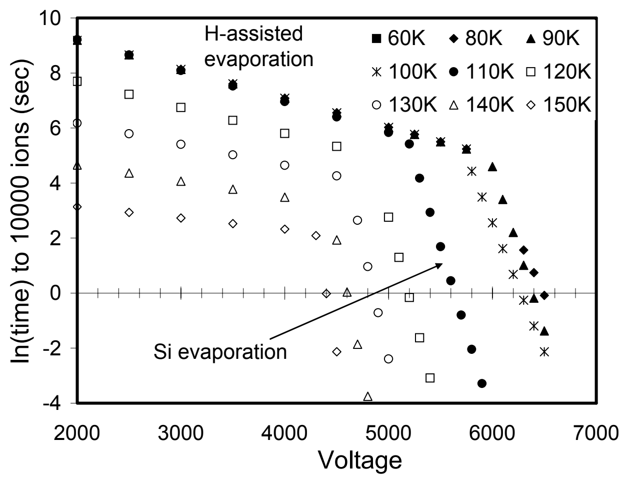

Fig. 1. Time to evaporate 10,000 Si ions as a function of temperature in high-resistivity Si. In the H-assisted evaporation mode, ~ 1% of the spectrum consists of H.

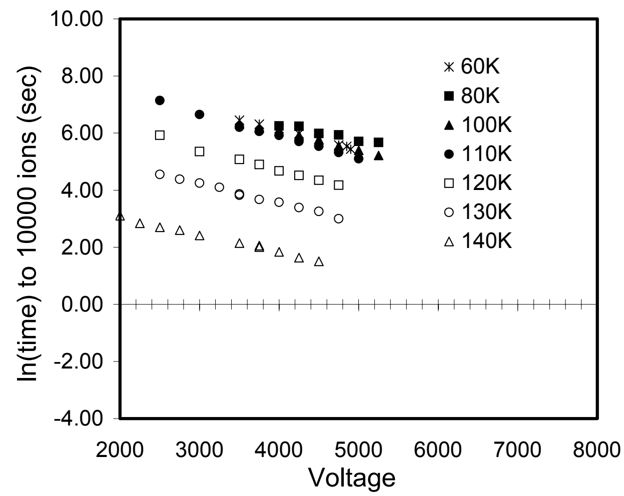

Fig. 2. Time to evaporate 10,000 Si ions as a function of temperature and voltage (field) for low-resistivity Si.

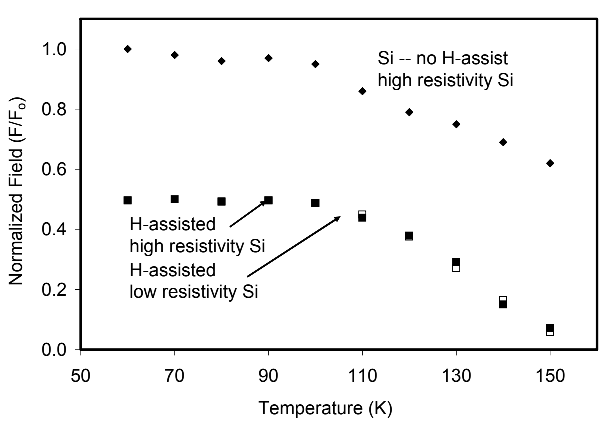

Fig. 3. Normalized field required to evaporate 10,000 Si ions in a given amount of time.

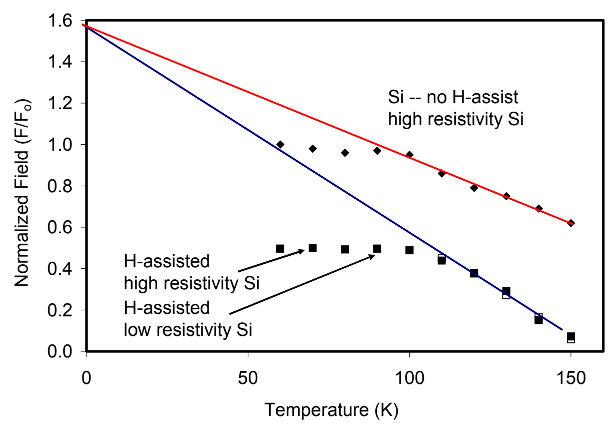

Fig. 4. Extrapolation of data from Fig. 3.

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