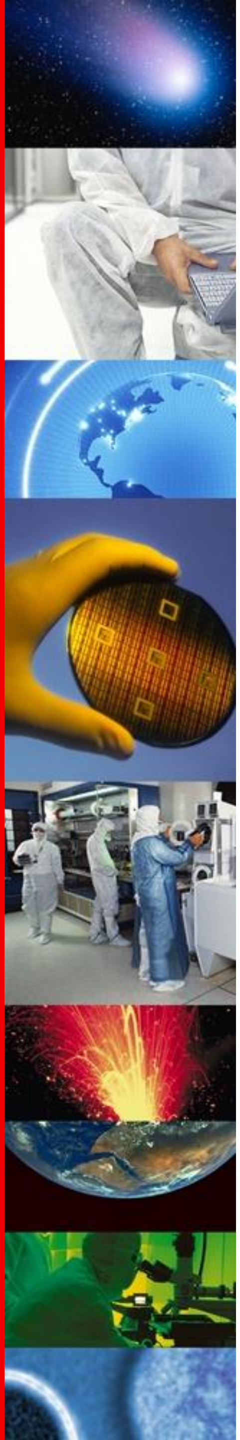

Novel Evaporation Control Concepts

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Motivation for Improvements in Instrument Control

1. Specimen survivability (analysis yield) for complex specimens is less than 100%
2. Advanced users often implement manual instrument control methods to improve yield
   - Manually adjustment of data rate during difficult-to-analyze regions
   - Adjustment of laser pulse energy and/or base temperature to reduce evaporation field
   - Modify voltage and/or rate in anticipation of rapid local changes in specimen evaporation based on experience (e.g. previous failures)
3. Current instrument control schemes do not necessarily utilize the full range of information available to optimize yield
4. Might a modified instrument control scheme lead to a better atom probe? Can we optimize tradeoffs between yield and data quality during the length of an analysis?

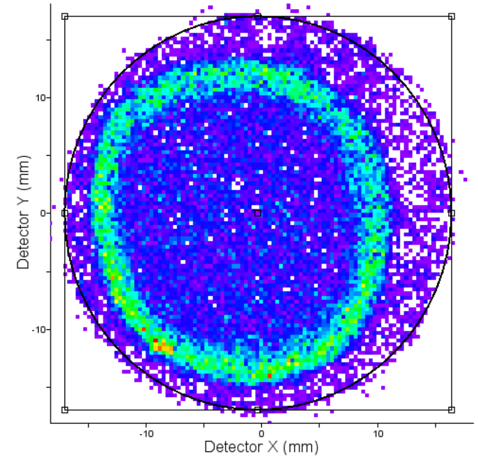
Guiding principle for maximizing specimen survivability:

- *Reducing the evaporation field for a given specimen increases chance for analysis success*

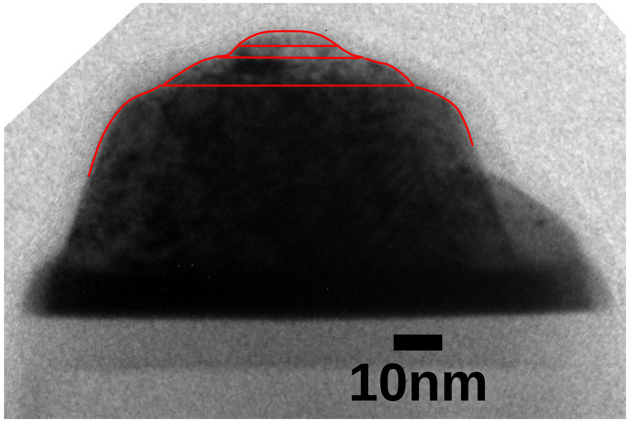
Multilayer Film Example

Experimental

Detector Maps



Specimen Shapes



E. A. Marquis et al., Journal of Microscopy 241(3) (2011) 225

Outline

- Current instrument control scheme
  - Voltage control to achieve desired data rate
  - Primary feedback metric is *mean detected events per pulse* collected across *entire detector area*
- Examples and ideas for discussion
  - Improvements to voltage control algorithm
  - Constant ion flux
  - Constant charge-state-ratio
  - User-defined control
- Discussion

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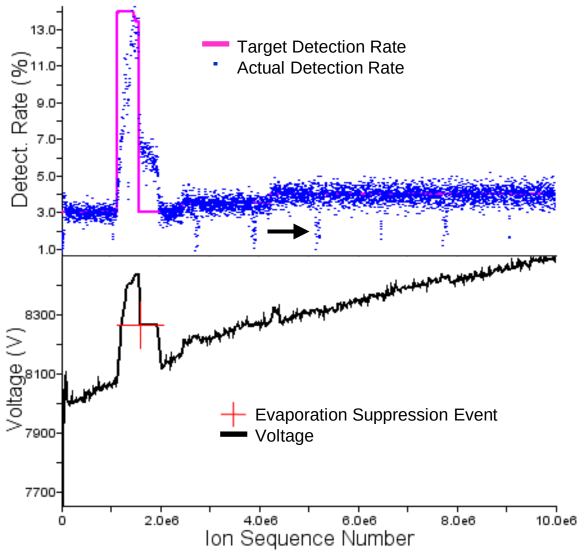
APT Instrument Control

Voltage variation to maintain target data rate

- <u>Basic Algorithm</u>
  - Voltage is changed to keep detection rate (DR) near chosen target (proportional control)
  - Adjustable parameters dictate frequency and size of adjustments based on difference between target and actual DR



- <u>Motivation</u>
  - Ease of implementation
  - Provides relatively constant evaporation field for homogeneous materials
    - Imaged tip area generally increases with voltage

- <u>Criticisms</u>
  - Many materials being analyzed are not homogeneous – field is not constant
  - Specimen survival rates (yield) need to improve

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Simple Algorithm Modification

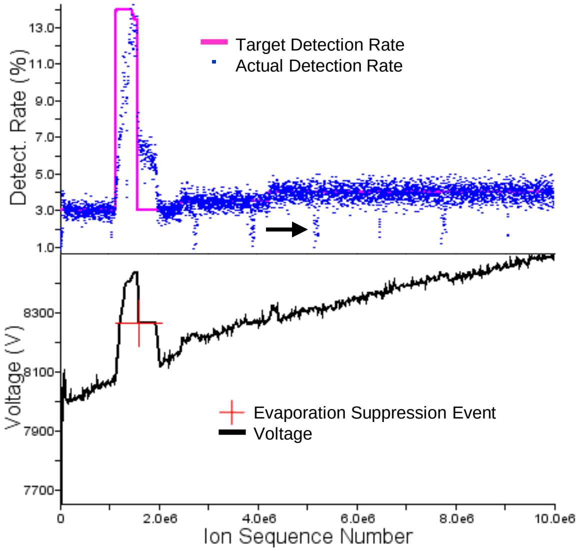
Are there any identifiable signals to indicate imminent specimen fracture? Can fracture be avoided?

Yield enhancement possibility

- Short timeframe surges in data rate may indicate increased potential for specimen fracture
- Immediately reduce voltage/rate when these occur to increase survivability

Software implementation

- Analyze response in order to detect rates that greatly exceed the target rate over a small number of pulses
- Immediately tell the hardware to temporarily stop pulsing and lower the voltage when some threshold rate is exceeded



Faster hardware implementation

- Data rates set at 1 event per 100 pulses should rarely experience 9/10 pulses with an event
- Immediately lower the voltage when this occurs

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General Background

Consider a typical homogeneous specimen

$$F = \frac{V}{kR}$$

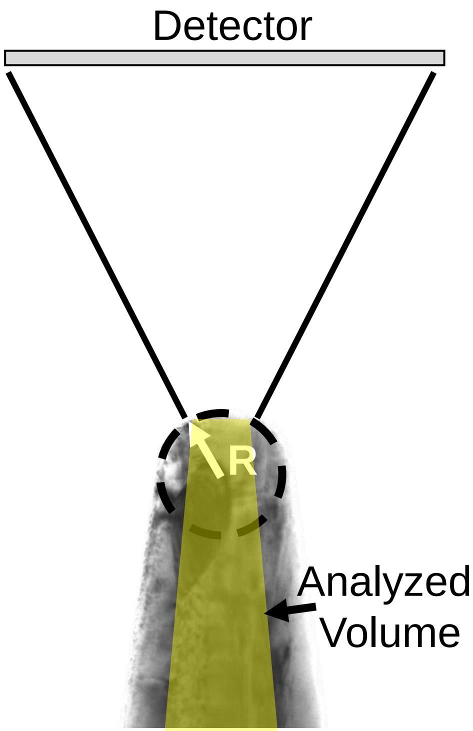
$ER \sim F^n \; (n > 10)$

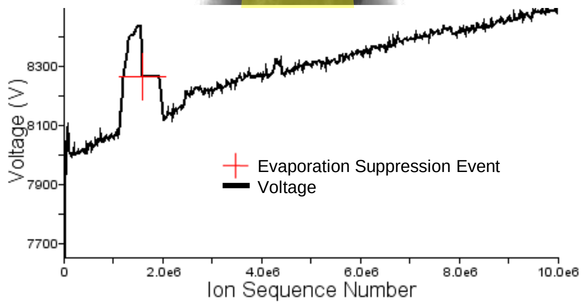
General relationships (Ion Flux)

- Specimens blunt (apex radius (R) increases) during analysis due to non-zero shank angle – imaged tip area increases
- Constant evaporation rate (ER) requires a constant evaporation field (F) → DR and ER are not the same if the radius is changing
- Voltage (V) increases during analysis to offset increasing R
- ER (ions/nm^2/s) generally decreases during analysis

Laser pulsing (Temperature and Charge State Ratio (CSR))

- Field is Temperature dependent (F decreases as T increases)
- Heated volumes increase as a specimen blunts leading to lower apex temperatures
- Elemental charge-state-ratio (CSR) for evaporated ions is an indication of F (the higher the proportion of large charge states, the higher the evaporation field)
- Higher CSRs generally indicate increasing evaporation fields for constant laser pulse energy analysis
- CSRs generally indicate tip cooling during analysis





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Constant Ion Flux

For a specimen with isotropic field evaporation properties, the following occurs:

- Specimen blunts during the course of the run
- Voltage increases to maintain detection rate
- Imaged area (projection of specimen surface onto detector) increases
- Evaporation rate (ions emitted *per unit area*) decreases

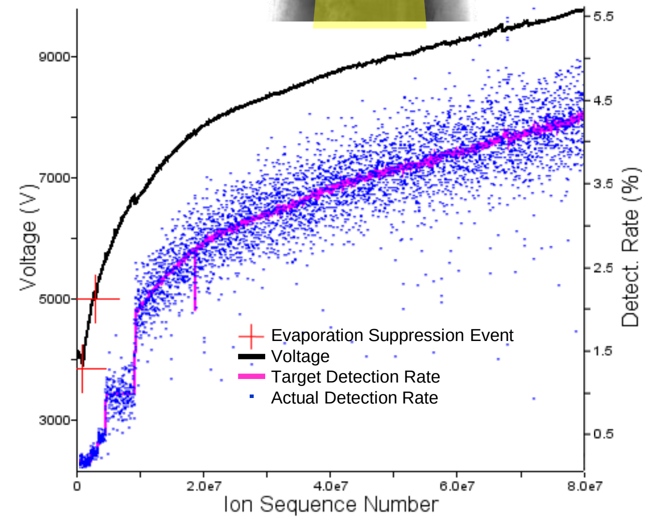
This causes

- Evaporation field decreases over time

(reconstruction accuracy degrades)

- Background signal increases over time

(decreasing data quality)



Implementation of constant ion flux correction

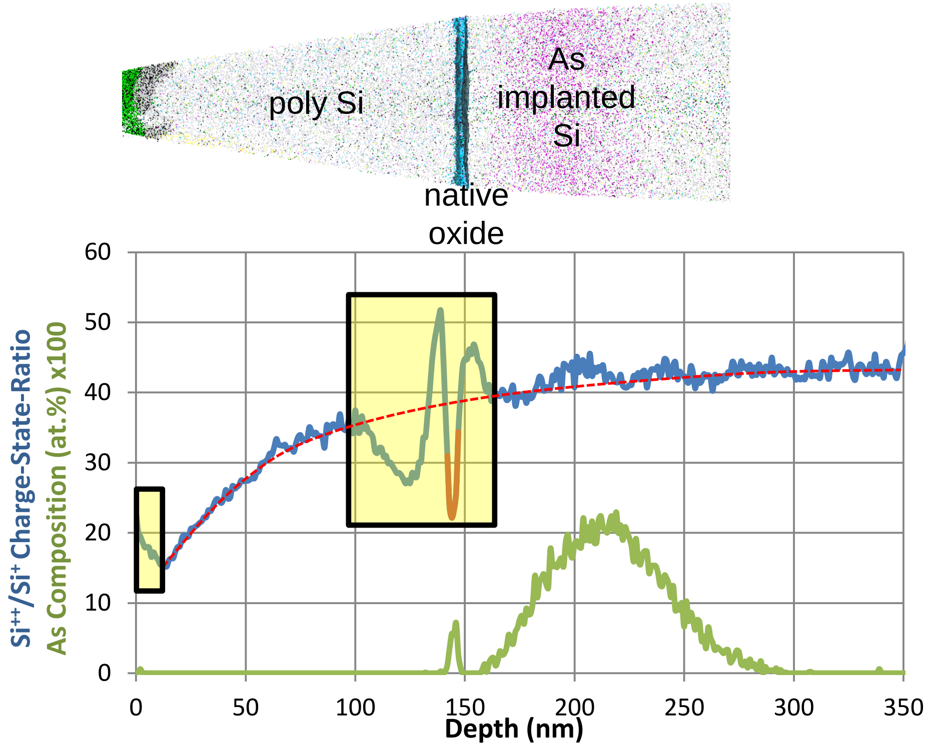
- Estimate the surface area change as a function of voltage
- Increase the data rate set point as voltage increases to maintain constant ion flux

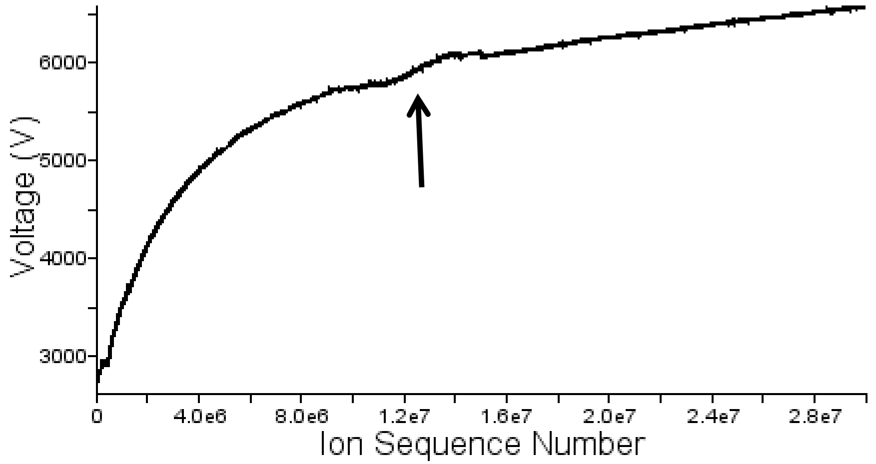
Discussion

- Evaporation field increases (relative to standard algorithm) and may promote fracture
- Estimates of surface area become complicated for specimens containing multiple phases

Constant Charge State Ratio

- CSR varies due to both tip shape evolution and apex temperature
- Change laser pulse energy to compensate for changing heated volume (constant evaporation field for homogeneous specimens)





<u>Considerations</u>

- Must have the particular CSR available <u>throughout</u> the analyzed volume
- V and DR are variables that are always well defined
- Flux and CSR depend on estimated evaporation field and atom type respectively – they are not always well defined
- Any algorithms must be prepared to handle ill-defined inputs

Scripted Control

Multiple Control Algorithms

- For an arbitrary specimen/application the user may need to define conditions for changing control algorithms and/or algorithm parameters
- Example: Low field material (A) on high field material (B)
  - Difficulty analyzing through the interface
  - A potential solution is lowering DR while near the interface
- Implementation
  - Track composition
  - Use algorithm 1 with parameters 1a while concentration of A >= 90%
  - At phase transition, when A<90% use algorithm 2 with parameters 2a
  - When B>95% wait 1 million ions and then use algorithm 3 with parameters 3a
- Possible algorithms
  - Voltage control
  - Constant flux – Local DRs
  - Constant CSR