Appendix A

Procedures for Monitoring in a Few Commercial Systems

The main monitoring tool addressed here is the Schottky plot. At the end we will briefly address the recording of (part of) the facet emission pattern in the Quanta 200F scanning electron microscope (SEM).

Key to useful Schottky plot data from commercial systems are creating a field-free zone between the extractor and the beam-defining aperture (or at least zero lens effect), and making the beam path free from obstructions from the beam-defining aperture to the entrance aperture of a Faraday cup on the stage.

The apertures that can be used as beam-defining apertures for Schottky plot recording are for the:

NOVA NanoSEM: the 2nd extractor aperture (acceptance half-angle 3.45 mrad)

Quanta 3D FEG: the aperture after the C0 lens (acceptance half-angle 1.99 mrad)

Quanta 200F: the decelerating lens aperture (acceptance half-angle 1.34 mrad)

For the Quanta 200F the zone between the extractor and the beam-defining aperture can be made field free by turning off the C1 and C2 lenses. The objective lens is then used to focus the beam into the Faraday cup aperture.

For the Quanta 3D FEG the zone between the extractor and the beam-defining aperture can be made field free by turning off the C0 lens. For both the NOVA NanoSEM and the Quanta 3D FEG, to ensure a free beam path beyond the beam-defining aperture, the C1 and C2 lenses are used to make crossovers, with the C2 lens crossover

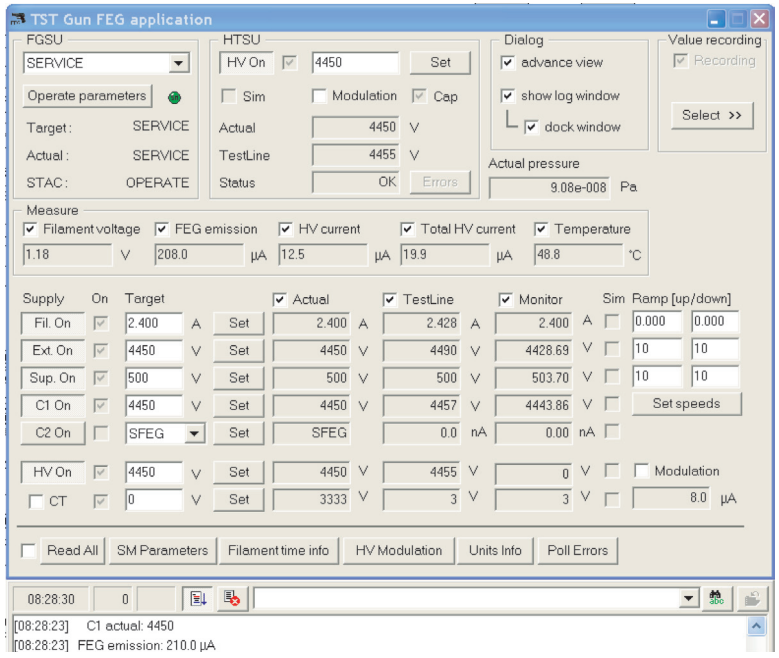
onto the decelerating lens aperture. Note that when the extraction voltage is changed, the lens effect between the extractor and the C1 lens is also changed. It may be required, for each data point, to manually optimize the settings of the condenser system (C1 C2) to get all current through the decelerating lens aperture.

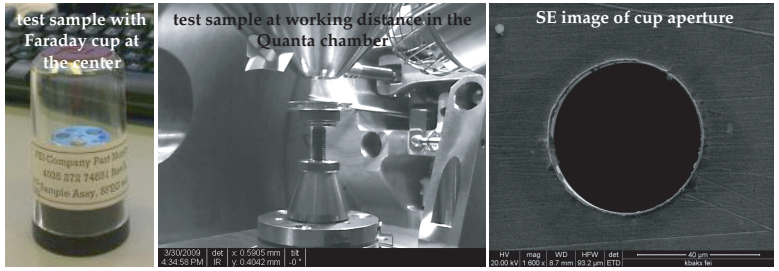
A.1 Recording Schottky Plots in Quanta 3D FEG and NOVA NanoSEM Systems

- Log on as "support" so that you are allowed to change the voltage settings of the electron gun.
- Vent the chamber.
- Put a Faraday cup on the stage (e.g., the one on a standard FEI* test sample).
- Free the beam path:
  - o Remove the "insert" from the objective lens, if present, and leave the "insert" inside chamber (check the manual; use the designated tool).
  - o Change to the largest aperture on the strip (1 mm diameter).
- Connect the Faraday cup to a current meter.
- Pump down the chamber.
- Bring the stage to a working distance.
- Change the configuration in "8_system configuration" to high vacuum mode.
- Quanta 3D FEG: go to spot 4.0, 10 kV beam energy; NOVA NanoSEM: go to spot 6.0 (the condenser systems of these machines are calibrated to give a focus on the decelerating lens aperture for these settings).
- Switch on the beam.
- Optimize the crossover position.
- Focus on the aperture of the Faraday cup in "quad 1" (top-left window).
- Go to the TstEGun window. Check the "advance view" box, if not checked.

*FEI Beam Technology Division, 5350 NE Dawson Creek Dr., Hillsboro, OR 97124, USA.

- Write down any relevant parameter values (date, system, heating current, heating voltage, gun pressure, total emission current, Coulomb tube (CT) current, extraction voltage, suppressor voltage, C1 lens setting, etc.).
- Turn off the beam.
- Change the operating mode from OPERATE to SERVICE. (N.B. The software Software can return a message, which you can "hide").
- Check the C1 lens voltage. Set it at the same value as it was in the OPERATE mode, if it has changed.
- Turn the beam on by pressing "HV on" in the TstEGun window (either of the two buttons).
- Change the ramping speeds for suppressor and extractor voltage from 0 V to 10 V for both up and down. Press "set speeds" to confirm.
- Go from scan mode to spot mode and put the spot inside the aperture.
- Write down V_{ext} ("Actual" value), V_{sup} ("Actual" value), I_{total} (FEG emission), I_{cup} (current meter), and the time in a table.
    1. Change from spot mode to scan mode.
    2. Reduce V_{ext} with 100 V.
    3. Change V_{sup} proportional to the V_{ext} change. This is to maintain the same field form around the tip (e.g., going from a 5.0 kV and 500 V to a 4.9 kV extraction voltage requires a suppressor voltage of 4.9/5.0 × 500 V).
    4. Go to spot mode and put the beam inside the cup (optional: check that the crossover position is still optimal).
    5. Write down V_{ext}, V_{sup}, I_{total}, I_{cup}, and the time in the table.
- Repeat the above five steps for the desired number of voltage settings. Check at one of the lower extraction voltages if the crossover is still looking OK and if all of the beam still goes into the Faraday cup.
- Bring back the settings to the settings of OPERATE mode.
- Beam off.
- Bring the extractor and the suppressor voltage back to the settings of OPERATE mode (see the top part of your filled out source monitoring work sheet). **Wait until the values are set.**





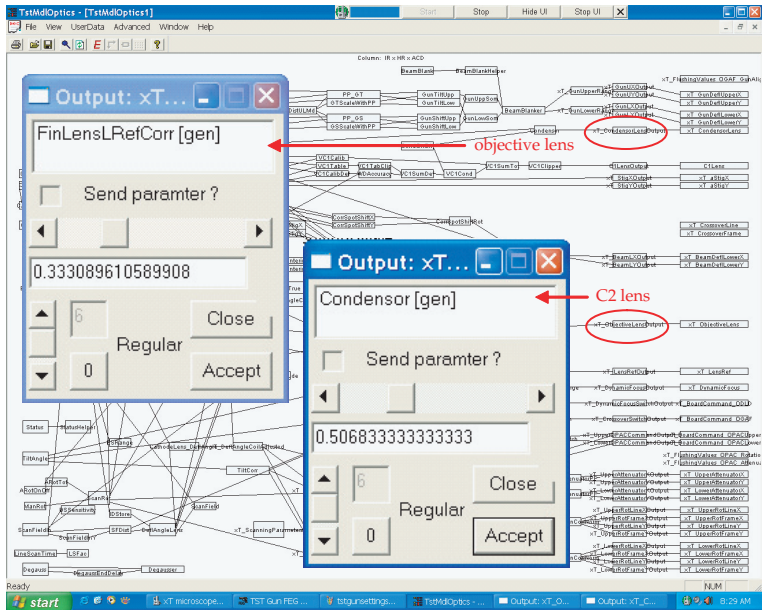
- Change ramping speeds of the extraction and the suppressor voltage from 10 to 0 (do not forget to press “set speeds”).
- Change from SERVICE mode to OPERATE mode.
- Set back the aperture number from 1 mm to what it was before the measurement.
- Beam on and check the system by imaging something at high resolution.
- Beam off.
- Vent the chamber.
- Take out the Faraday cup.

- Put the "insert" back into the objective lens.
- Check Part III on the source monitoring sheet.
- Pump the chamber.
- Set the system configuration back from "high vacuum mode" to the setting that belongs to the "insert."
- Log off.
- Analyze the data and extract the field enhancement factor. Has it changed with respect to the last time, and what is the field strength the source is operating at?

Recording Schottky plots in the Quanta 200F system:

- Log on as "support" to be able to change the voltage settings.
- Vent the chamber.
- Put a Faraday cup on the stage (e.g., the standard FEI test sample).
- Free the beam path:
    - Remove the "insert" from the objective lens, if present (see the manual), and leave the "insert" inside the chamber.
    - Check if the blanker is present? Set it to the largest separation: setting 4.
    - Change to the largest aperture on the strip (number 1, 1 mm diameter).
- Connect the Faraday cup to a current meter.
- Pump down the chamber.
- Bring the stage to a working distance.
- Switch on the beam.
- Set the source tilt to zero.
- Focus on the aperture of the Faraday cup in "quad 1" (top-left window).
- Go to the TstEGun window. Check the "advance view" box.
- Write down any relevant parameter values (date, system, heating current, heating voltage, total emission current, CT current, extraction voltage, suppressor voltage, etc.).
- Turn off the beam.
- Change the operating mode to SERVICE. (N.B. The software returns a message, which you can "hide").
- Turn the beam on by pressing "HV on" in the TstEGun window (either of the two buttons).

- Change the ramping speeds for the suppressor and the extractor voltage to 10 V for both up and down. Press "set speeds."
- Turn off the CT (clear the box) (means it goes to ground potential).
- Change V_{C1} in the "Target" column to the V_{ext} value (press the set button or use Enter to confirm) (N.B. By doing this the potential on the C1 lens becomes zero with respect to ground).
- Change *HV* in the "Target" column to the V_{ext} value (press the set button or use Enter to confirm) (N.B. By doing this the potential on the extractor becomes zero with respect to ground).
- Go to the TstEOptics window. Open the xT_ObjectiveLensOutput window (objective/final lens) and the xT_CondensorLensOutput window (C2 lens).



- Set the condenser lens excitation (C2 lens) to zero. Watch the image of the Faraday cup aperture and adjust the objective lens setting if you start to lose track of the hole.
- If necessary focus a little bit by optimizing the objective lens setting.

- Go from scan mode (full frame) to spot mode and put the spot inside the aperture.
- Check the current meter reading to make sure all current is going into the cup.
- Check if the alignment of the aperture on the stick is such that all current passes it: do this by changing its alignment and monitor the current reading from the cup and maximize it.
- Write down V_{ext} ("Actual" value), V_{sup} ("Actual" value), I_{total} (FEG emission), I_{CT} (bottom right in the TstEGun window), I_{cup} (current meter), and the time in a table.
    1. Change from spot mode to scan mode.
    2. Reduce V_{ext} with 100 V.
    3. Change V_{sup} proportional to the V_{ext} change. This is to maintain the same field form around the tip (e.g., going from a 5.0 kV and 500 V to a 4.9 kV extraction voltage requires a suppressor voltage of 4.9/5.0 × 500 V).
    4. Set V_{C1} to the same value as the extractor.
    5. Set *HV* to the same value as the extractor.
    6. Set the condenser lens excitation to zero.
    7. If necessary focus a little bit on the aperture with the objective lens.
    8. Go to spot mode and put the beam inside the cup.
    9. Write down V_{ext}, V_{sup}, I_{total}, I_{CT}, I_{cup}, and the time in a table.
- Repeat the above nine steps for the desired number of voltage settings.
- Turn of the beam.
- Bring back the extractor and the suppressor voltage to the settings of OPERATE mode (see the top part of your filled out source monitoring work sheet). **Wait until the values are set.**
- Change ramping speeds of the extraction and the suppressor voltage from 10 to 0 (do not forget to press "set speeds").
- Change from SERVICE mode to OPERATE mode.
- Set back the aperture number from 1 to what it was before the measurement.
- Beam on and check the system by making a high-resolution image.
- Beam off.

- Vent the chamber.
- Take out the Faraday cup.
- Put the "insert" back into the objective lens, if required.
- Pump the chamber.
- Log off.
- Analyze the data and extract the field enhancement factor. Has it changed with respect to the last time, and what is the field strength the source is operating at?

A.2 Imaging of the Facet in the Quanta 200F System

The Quanta 200F extractor accepts part of the total facet beam: its acceptance half-angle is ~66 mrad (3.8°). If the C1 lens is turned off (same voltage as the extractor) or collimates the beam, the beam intensity profile in the CT behind the C1 lens is part of the facet emission pattern.

The intensity profile of the beam in the CT can be measured by scanning the beam across the CT aperture by using "gun tilt" and collecting the current through the aperture in a Faraday cup on the stage.

The gun tilt can be changed manually in the TstEOptics menu under "Gun tilt," with a maximum range of –1 to 1 for both *x* and *y*. The "Gun tilt" setting determines which part of the beam is selected by the CT aperture. This is done by changing the settings of the two sets of deflector plates, which are positioned somewhere along the CT. Because there are two sets of deflectors the pivot point can be maintained at the same height. This is done automatically when changing the gun tilt.

The divergence or collimation of the facet beam leaving the extractor can be tuned by changing the spot number (which changes the C1 lens setting): the part of the beam that is scanned by changing the gun tilt settings increases with increasing spot number. If the beam diameter at the CT aperture becomes smaller than the aperture size the recorded image will start showing the shadow image of the extractor aperture.

Appendix B

Procedure to Characterize System Performance

The performance of a probe-forming system can be characterized if the following parameters are available:

Source: practical brightness, FW50 energy spread, extraction voltage, virtual source size (B, ΔE, V_{ext}, d_v)

Column: spherical and chromatic aberration coefficients of the final lens (C_S, C_C)

Gun: spherical and chromatic aberration coefficients of the gun lens (C_{Sg}, C_{Cg})

Target: beam energy (V_p)

Key is which probe size contributions are dominant at the desired probe current level?

Approach: Calculate the parameters below and follow the scheme to find (1) which probe size contributions are dominant for your system at the probe current of interest, (2) the optimum probe size, (3) the associated half opening angle of the beam, and (4) the magnification of the virtual source.

Calculate $I_{AI} = 1.08 \cdot 10^{-18} B$ (I for which $d_A = d_I$)

Calculate $\delta_{CA} = 1.99 \cdot 10^{-5} \sqrt{C_C \frac{\Delta E}{V_p^{3/2}}}$ and $\delta_{SA} = 8.46 \cdot 10^{-8} \left(\frac{C_S}{V_p^{3/2}} \right)^{1/4}$

Calculate $I_{AC_g} = 2.72 \cdot 10^{-9} \frac{B V_{ext}^{3/2} d_v^2}{C_{Cg} \Delta E}$ (I for which $d_A = d_{Cg}$) and $I_{AS_g} = 1.50 \cdot 10^{-4} \frac{B V_{ext}^{3/4} d_v^2}{C_{Sg}^{1/2}}$ (I for which $d_A = d_{Sg}$)

Calculate $I_{ICg} = \dfrac{I_{ACg}^2}{I_{AI}}$ and $I_{ISg} = \left(\dfrac{I_{ASg}^2}{\sqrt{I_{AI}}} \right)^{2/3}$

(I for which $d_I = d_{Sg}$)

Is the desired probe current below I_{AI}?

$\delta_{CA} > \delta_{SA}$: d_C balances d_A $\rightarrow d_p$ from Table B.1; α and M from Table B.2
$\delta_{CA} < \delta_{SA}$: d_S balances d_A

Is the desired probe current between I_{AI} and the smallest of (I_{ISg},I_{ICg})?

$\delta_{CA} > \delta_{SA}$: d_C balances d_I $\rightarrow d_p$ from Table B.1; α and M from Table B.2
$\delta_{CA} < \delta_{SA}$: d_S balances d_I

Is the desired probe current larger than the smallest of (I_{ISg},I_{ICg})?

$I_{ICg} > I_{ISg}$:
$\delta_{CA} > \delta_{SA}$: d_C balances d_{Sg} $\rightarrow d_p$ from Table B.1; α and M from Table B.2
$\delta_{CA} < \delta_{SA}$: d_S balances d_{Sg}
$I_{ICg} < I_{ISg}$:

desired probe current smaller than I_{CgSg}?

$\delta_{CA} > \delta_{SA}$: d_C balances d_{Cg} $\rightarrow d_p$ from Table B.1; α and M from Table B.2
$\delta_{CA} < \delta_{SA}$: d_S balances d_{Cg}

desired probe current larger than I_{CgSg}?

d_{Cg} balances d_{Sg} $\rightarrow d_p$ from Table B.1; α and M from Table B.2

Table B.1 Optimum total probe size d_p for the desired probe current for a balance between d_A, d_I, d_{Cg} or d_{Sg}, and d_C or d_S. Also given is the figure of merit (fm) for column and source

	d_C			d_S		
	d_p (m)	fm column	fm source	d_p (m)	fm column	fm source
d_A	$\sqrt{2}\delta_{CA}$	$\dfrac{1}{C_C}$	$\dfrac{1}{\Delta E}$	$1.15\delta_{SA}$	$\dfrac{1}{C_S}$	-
d_I	$\sqrt{2}\delta_{CA}\left(\dfrac{I}{I_{AI}}\right)^{1/4}$	$\dfrac{1}{C_C}$	$\dfrac{B}{\Delta E^2}$	$1.54\delta_{SA}\left(\dfrac{I}{I_{AI}}\right)^{3/8}$	$\dfrac{1}{C_S}$	B

	d_C			d_S		
	d_p (m)	fm column	fm source	d_p (m)	fm column	fm source
d_{Cg}	$\delta_{CA}\left(\frac{I}{I_{ACg}}\right)^{1/2}$	$\frac{1}{C_C C_{Cg}}$	$\frac{V_{ext}^{3/2} B d_v^2}{\Delta E^2}$	$\sqrt{2}\delta_{SA}\left(\frac{I}{I_{ACg}}\right)^{3/4}$	$\frac{1}{C_S C_{Cg}^{3/4}}$	$\frac{V_{ext}^{3/2} B d_v^2}{\Delta E}$
d_{Sg}	$\sqrt{2}\delta_{CA}\left(\frac{I}{I_{ASg}}\right)^{1/1}$	$\frac{1}{C_C C_{Sg}}$	$\frac{V_{ext}^{3/4} B d_v^2}{\sqrt{\Delta E}}$	$1.75\delta_{SA}\left(\frac{I}{I_{ASg}}\right)^{3/2}$	$\frac{1}{C_S C_{Sg}^{3/4}}$	$V_{ext}^{3/4} B d_v^2$

Table B.2 Optimum magnification of the virtual source, M, and optimum half opening angle of the beam at the target, α_p, for different regimes in which two balancing contributions dominate the total probe size

	d_C		d_S	
	M	$\alpha_{p,opt}$ (rad)	M	$\alpha_{p,opt}$ (rad)
d_A	–	$\frac{6.62\cdot10^{-10}}{\sqrt{V_p}\delta_{CA}}$	–	$\frac{6.18\cdot10^{-10}}{\sqrt{V_p}\delta_{SA}}$
d_I	$\sqrt{2}\frac{d_p}{d_v}$	$\frac{6.62\cdot10^{-10}}{\sqrt{V_p}\delta_{CA}}\left(\frac{I}{I_{AI}}\right)^{1/4}$	$0.80\frac{d_p}{d_v}$	$\frac{4.63\cdot10^{-10}}{\sqrt{V_p}\delta_{SA}}\left(\frac{I}{I_{AI}}\right)^{1/8}$
d_{Cg}	$\left(\frac{C_C}{C_{Cg}}\right)^{1/2}\left(\frac{V_g}{V_p}\right)^{3/4}$	$\frac{6.62\cdot10^{-10}}{\sqrt{V_p}\delta_{CA}}\left(\frac{I}{I_{ACg}}\right)^{1/2}$	$\frac{\delta_{SA}}{d_v}\frac{I_{ACg}^{1/4}}{\sqrt{I_{AI}}}I^{1/4}$	$\frac{6.62\cdot10^{-10}}{\sqrt{V_p}\delta_{SA}}\left(\frac{I}{I_{ACg}}\right)^{1/4}$
d_{Sg}	$\frac{\delta_{CA}}{d_v}\frac{I_{ASg}}{\sqrt{I_{AI}}}\frac{1}{\sqrt{I}}$	$\frac{6.62\cdot10^{-10}}{\sqrt{V_p}\delta_{CA}}\left(\frac{I}{I_{ASg}}\right)^{1/1}$	$\left(\frac{C_S}{C_{Sg}}\right)^{1/4}\left(\frac{V_g}{V_p}\right)^{3/8}$	$\frac{6.62\cdot10^{-10}}{\sqrt{V_p}\delta_{SA}}\left(\frac{I}{I_{ASg}}\right)^{1/2}$

Bibliography

1. S. Babin, M. Gaevsky, D. Joy, M. Machin, A. Martynov, *J. Vac. Sci. Technol. B*, **24** (2006), 2956.
2. A. S. Bahm, G. A. Schwind, L. W. Swanson, *J. Vac. Sci. Technol. B*, **26** (2008), 2080.
3. J. P. Barbour, F. M. Charbonnier, W. W. Dolan, W. P. Dyke, E. E. Martin, J. K. Trolan, *Phys. Rev.*, **117** (1960), 1452.
4. J. E. Barth, P. Kruit, *Optik*, **101** (1996), 101.
5. J. E. Barth, M. D. Nykerk, *Nucl. Instrum. Methods*, *Phys. Res. A*, **427** (1999), 86.
6. A. E. Bell, L. W. Swanson, *Phys. Rev. B*, **19** (1979), 3353.
7. K. Besocke, H. Wagner, *Phys. Rev. B*, **8** (1973), 4597.
8. K. Besocke, B. Krahl-Urban, H. Wagner, *Surf. Sci.*, **68** (1977), 39.
9. P. C. Bettler, G. G. Love, *J. Appl. Phys.*, **38** (1967), 3835.
10. P. C. Bettler, G. Barnes, *Surf. Sci.*, **10** (1968), 165.
11. P. C. Bettler, D. H. Bennum, C. M. Case, *Surf. Sci.*, **44** (1974), 360.
12. H. Boersch, *Z. Phys.*, **139** (1954), 115.
13. C. Bombis, A. Emundts, M. Nowicki, H. P. Bonzel, *Surf. Sci.*, **511** (2002), 83.
14. H. P. Bonzel, *Phys. Rep.*, **385** (2003), 1.
15. A. S. Carasso, D. S. Bright, A. E. Vladár, *Opt. Eng.*, **41** (2002), 2499.
16. S. P. Chen, *Surf. Sci. Lett.*, **274** (1992), L619.
17. S. G. Christov, *Phys. Status Solidi*, **17** (1966), 11.
18. *Charged Particle Optics*, http://www.electronoptics.com.
19. A. C. Crewe, in *Handbook of Charged Particle Optics*, edited by J. Orloff (CRC, New York, 1997), Chap. 10, p. 406.

20. U. Dahmen, R. Erni, V. Radmilovic, C. Kisielowski, M.D. Rossell, P. Denes, *Philos. Trans. R. Soc. A*, **367** (2009), 3795.
21. L. R. Danielson, L. W. Swanson, *Surf. Sci.*, **88** (1979), 14.
22. L. R. Danielson, *J. Appl. Phys.*, **52** (1981), 6769.
23. M. Degawa, K. Thürmer, E. D. Williams, *Phys. Rev. B*, **74** (2006a), 155432.
24. M. Degawa, K. Thürmer, E. D. Williams, *Jpn. J. Appl. Phys.*, **45** (2006b), 2070.
25. A. K. Dokania, J. F. M. Velthuis, Y. Zhang, P. Kruit, *J. Vac. Sci. Technol. B*, **25** (2007), 504.
26. A.K. Dokania, M. Pelle, P. Kruit, *Microelectron. Eng.*, **85** (2008), 1031.
27. W. P. Dyke, F. M. Charbonnier, R. W. Strayer, R. L. Floyd, J. P. Barbour, J. K. Trolan, *J. Appl. Phys.*, **31** (1960), 790.
28. A. B. El-Kareh, J. C. Wolfe, J. E. Wolfe, *J. Appl. Phys.*, **48** (1977), 4749.
29. A. Ferriere, L. Lestrade, J-F. Robert, *J. Solar Energy Eng.*, **122** (2000), 9.
30. J. H. Fink, B. W. Schumacher, *Nucl. Instrum. Methods*, **130** (1975), 353.
31. R. G. Forbes, *J. Vac. Sci. Technol. B*, **26** (2008), 788.
32. M. J. Fransen, E. P. N. Damen, C. Schiller, T. L. van Rooy, H. B. Groen, P. Kruit, *Appl. Surf. Sci.*, **94–95** (1996), 107.
33. M. J. Fransen, J. S. Faber, T. L. van Rooy, P. C. Tiemeijer, P. Kruit, *J. Vac. Sci. Technol. B*, **16** (1998), 2063.
34. M. J. Fransen, T.L. de Rooy, P. C. Tiemeijer, M. H. F. Overwijk, J. S. Faber, P. Kruit, *Adv. Imag. Electron Phys.*, **111** (1999), 91.
35. M. J. Fransen, M. H. F. Overwijk, P. Kruit, *Appl. Surf. Sci.*, **146** (1999), 357.
36. S. Fujita, H. Shimoyama, *J. Electron Microsc.*, **54** (2005), 331.
37. S. Fujita, H. Shimoyama, *J. Electron Microsc.*, **54** (2005), 413.
38. S. Fujita, H. Shimoyama, *J. Vac. Sci. Technol. B*, **24** (2006), 1891.
39. S. Fujita, H. Shimoyama, *Phys. Rev. B*, **75** (2007), 235431.
40. G. Fursey, in *Field Emission in Vacuum Microelectronics*, edited by I. Brodie, P. Shwoebel, (Kluwer Academic/Plenum Publishers, New York, 2005), Chap. 7, p. 115.
41. M. Gesley, *J. Vac. Sci. Technol. B*, **9** (1991), 2949.
42. M. Giesen, G. Schulze Icking-Konert, H. Ibach, *Phys. Rev. Lett.*, **80** (1998), 552.
43. M. Giesen, *Prog. Surf. Sci.*, **68** (2001), 1.

44. M. Giesen, G. Beltramo, S. Dieluweit, J. Müller, H. Ibach, W. Schmickler, *Surf. Sci.*, **595** (2005), 127.
45. J. B. McGinn, S. G. den Hartog, D. S. Jun, G. G. Magera, G. A. Schwind, United States Patent 6680562 B1 (2004).
46. R. Gomer, L. W. Swanson, *J. Chem. Phys.*, **38** (1963), 1613.
47. D. J. Griffiths, *Introduction to Quantum Mechanics* (2nd ed.) (Prentice Hall, 2004), Chap. 8, p. 315.
48. G. A. Haas, in *The American Institute of Physics Handbook*, 3rd ed., edited by D. E. Gray (McGraw-Hill, 1972), pp. 9-172–9-186.
49. P. W. Hawkes, E. Kasper, *Principles of Electron Optics*, Vol. 2 (Academic Press, London, 1996), Chap. 47, p. 971.
50. P. W. Hawkes, E. Kasper, *Principles of Electron Optics*, Vol. 2 (Academic Press, London, 1996), Chap. 44, p. 924.
51. C. Herring, M. H. Nichols, *Rev. Mod. Phys.*, **21** (1949), 185.
52. C. Herring, in *The Physics of Powder Metallurgy*, edited by W. E. Kingston (McGraw–Hill, New York, 1951), Chap. 8, p. 143.
53. N. Hirai, K. Watanabe, S. Hara, *Surf. Sci.*, **493** (2001), 568.
54. M. Horn-Von Hoegen, F.-J. Meyer zu Heringdorf, D. Kähler, T. Schmidt, E. Bauer, *Thin Solid Films*, **336** (1998), 16.
55. W. Hu, X. Shu, B. Zhang, *Comput. Mater. Sci.*, **23** (2002), 175.
56. A. R. Hutson, *Phys. Rev.*, **98** (1955), 889; G. F. Smith, *Phys. Rev.*, **100** (1955), 1115.
57. H. Ibach, W. Schmickler, *Phys. Rev. Lett.*, **91** (2003), 016106.
58. H. Ibach, *Physics of Surfaces and Interfaces*, (Springer-Verlag, Berlin, Heidelberg, 2006), Chap. 4, p. 149.
59. A. Ichimiya, K. Hayashi, E. D. Williams, T. L. Einstein, M. Uwaha, K. Watanabe, *Appl. Surf. Sci.*, **175–176** (2001), 33.
60. Y. Irokawa, R. Mitsuhashi, S. Lee, K. Min, M. Inoue, Y. Kimura, R, Shimizu, *Jpn. J. Appl. Phys.*, **35** (1996), 4042.
61. N. Israeli, D. Kandel, *Phys. Rev. B*, **60** (1999), 5946.
62. S. C. Jain, V. Sinhas, B. K. Reddys, *J. Phys. D: Appl. Phys.*, **3** (1970), 1359.
63. G. H. Jansen, *Adv. Electron. Electron Phys.*, (Suppl. 21) (1990).
64. X. R. Jiang, P. Kruit, *Microelectron. Eng.*, **30** (1996), 249.
65. X. R. Jiang, *Coulomb Interactions in Charged Particle Optical Columns* (PhD thesis, Delft University of Technology, 1996), ISBN 90-407-1369-3.

66. N. de Jonge, *J. Appl. Phys.*, **95** (2004), 673.
67. D. C. Joy, *J. Microsc.*, **208** (2002), 24.
68. D. C. Joy, in *Characterization and Metrology for ULSI Technology 2005: Richardson*, *Texas*, *15-18 March 2005*, edited by D. G. Seiler, Paper no. CP 788, (American Institute of Physics, Melville, 2005), p. 535.
69. N. K. Kang, D. Tuggle, L. W. Swanson, *Optik*, **63** (1983), 313.
70. H. Kawano, *Prog. Surf. Sci.*, **83** (2008), 1.
71. E. C. Kemble, *Phys. Rev.*, **48** (1935), 549.
72. H. S. Kim, M. L. Yu, E. Kratschmer, B. W. Hussey, M. G. R. Thomson, T. H. P. Chang, *J. Vac. Sci. Technol. B*, **13** (1995), 2468.
73. H. S. Kim, M. L. Yu, M. G. R. Thomson, E. Kratschmer, T. H. P. Chang, *J. Vac. Sci. Technol. B*, **15** (1997), 2284.
74. H. S. Kim, M. L. Yu, M. G. R. Thomson, E. Kratschmer, T. H. P. Chang, *J. Appl. Phys.*, **81** (1997), 461.
75. W. Knauer, *Optik*, **59** (1981), 335.
76. E. Kratschmer, S. A. Rishton, D. P. Kern, T. H. P Chang, *J. Vac. Sci. Technol. B*, **6** (1988), 2074.
77. P. Kruit, M. Bezuijen, J. E. Barth, *J. Appl. Phys.*, **99** (2006), 024315.
78. P. Kruit, G. H. Jansen, in *Handbook of charged particle optics (Second Edition)*, edited by J. Orloff (CRC Press, New York, 2008), Chap. 7, p. 341.
79. M. V. Kuz'min, M. A. Mittsev, *Tech. Phys. Lett.*, **27** (2001), 437.
80. N. D. Lang, W. Kohn, *Phys. Rev. B*, **1** (1970), 4555.
81. N. D. Lang, W. Kohn, *Phys. Rev.*, **3** (1971), 1215.
82. R. R. Law, *Proc. Inst. Radio Eng.*, **25** (1937), 954.
83. S. C. Lee, Y. Irokawa, M. Inoue, R. Shimizu, *Surf. Sci.*, **330** (1995), 289.
84. J. A. Liddle, P. Naulleau, G. Schmid, *J. Vac. Sci. Technol. B*, **22** (2004), 2897.
85. D.-J. Liu, J. D. Weeks, M. D. Johnson, E. D. Williams, *Phys. Rev. B*, **55** (1997), 7653.
86. D. Liu, H. M. Lu, Q. Jiang, *J. Phys.: Condens. Matter*, **21** (2009), 198002.
87. A. Y. Lozovoi, A. Alavi, *Phys. Rev. B*, **68** (2003), 245416.
88. J. Mackenzie, A. J. W. Moore, J. F. Nicholas, *J. Phys. Chem. Solids*, **23** (1962), 185.
89. T. Matsumoto, A. Cezairliyan, D. Basak, *Int. J. Thermophys.*, **20** (1999), 943.

90. T. Matsumoto, A. Ono, G. Barreiro, paper presented at the Fourteenth Symposium on Thermophysical Properties, June 25–30, 2000, Boulder, Colorado, USA.
91. I. Merrick, J. E. Inglesfield, G. A. Attard, *Phys. Rev. B*, **72** (2005), 033403.
92. A. Modinos, *Field, Thermionic, and Secondary Electron Emission Spectroscopy*, (Plenum Press, New York, 1984), Chap. 1, p. 1.
93. A. Modinos, J. P. Xanthakis, *Surf. Sci.*, **249** (1991), 373.
94. J. Müller, H. Ibach, *Phys. Rev. B*, **74** (2006), 085408.
95. I. Müllerová, *Scan. Microsc.*, **13** (1999), 7.
96. W. W. Mullins, G. S. Rohrer, *J. Am. Ceram. Soc.*, **83** (2000), 214.
97. E. L. Murphy, R. H. Good, *Phys. Rev.*, **102** (1956), 1464.
98. Y. Neo, H. Mimura, T. Matsumoto, *Appl. Phys. Lett.*, **88** (2006), 073511.
99. F. A. Nichols, W. W. Mullins, *J. Appl. Phys.*, **36** (1965), 1826.
100. J. Orloff, L. W. Swanson, J.-Z. Li, *J. Vac. Sci. Technol. B*, **3** (1985), 224.
101. V. G. Pavlov, *Phys. Solid State*, **48** (2006), 720.
102. I. Petroff, C. R. Viswanathan, *Phys. Rev. B*, **4** (1971), 799.
103. T. Radlicka, B. Lencová, *Ultramicroscopy*, **108** (2008), 455.
104. F. H. Read, N. J. Bowring, *Rev. Sci. Instrum.*, **74** (2003), 2280.
105. F. H. Read, N. J. Bowring, *Nucl. Instrum. Methods A*, **519** (2004), 196.
106. L. Reimer, *Scanning Electron Microscopy: Physics of Image Formation and Microanalysis* (Springer, Berlin, 1998), Chap. 2, p. 53.
107. S. A. Rishton, S. P. Beaumont, C. D. W. Wilkinson, *J. Phys. E: Sci. Instrum.*, 17 (1984), 296.
108. A. M. Rodriguez, G. Bozzolo, J. Ferrante, *Surf. Sci.*, **289** (1993), 100.
109. S. Sakawa, K. Tsunoda, Y. Terui, *Surf. Interface Anal.*, **35** (2003), 11.
110. N. Samoto, R. Shimizu, H. Hashimoto, N. Tamura, K. Gamo, S. Namba, *Jpn. J. Appl. Phys.*, *1*, **24** (1985), 766.
111. G. A. Schwind, D. S. Jun, G. G. Magera, United States Patent 6798126 B2, 2004.
112. G. A. Schwind, G. Magera, L. S. Swanson, *J. Vac. Sci. Technol. B*, **24** (2006), 2897.
113. H. Shimoyama, S. Maruse, *Ultramicroscopy*, **15** (1984), 239.
114. V. N. Shrednik, V. G. Pavlov, A. A. Rabinovich, B. M. Shaikhin, *Phys. Status Solids A*, **23** (1974), 373.
115. J. A. Simpson, *Rev. Sci. Instrum.*, **32** (1961), 1283.

116. H. L. Skriver, N. M. Rosengaard, *Phys. Rev. B*, **46** (1992), 7157.
117. D. F. Stafford, A. H. Weber, *J. Appl. Phys.*, **34** (1963), 2667.
118. *Surface Explorer*, http://surfexp.fhi-berlin.mpg.de/.
119. L. W. Swanson, G. A. Schwind, in *Handbook of Charged Particle Optics*, edited by J. Orloff (CRC Press, New York, 1997), Chap. 2, p. 77.
120. L. W. Swanson, G. A. Schwind, in *Handbook of Charged Particle Optics (Second Edition)*, edited by J. Orloff (CRC Press, New York, 2008), Chap. 1, p. 1.
121. A. Szczepkowicz, R. Bryl, *Surf. Sci.*, **559** (2004), L169.
122. M. Takeguchi, M. Morikawa, C. Hanqing, R. Shimizu, K. Tsunoda, H. Hagiwara, H. Hiraoka, *Technol. Rep. Osaka Univ.*, **41** (1991), 267.
123. K. Tamura, M. Amano, W. Chu, H. Ishii, M. Owari, T. Kawano, T. Nagatomi, Y. Takai, C. Oshima, R. Shimizu, Y. Nihei, *Surf. Interface Anal.*, **37** (2005), 217.
124. H. Tanaka, H. Nakayama, K. Watanabe, *Jpn. J. Appl. Phys.*, **44** (2005), 7518.
125. S. Tanaka, N. C. Bartelt, C. C. Umbach, R. M. Tromp, J. M. Blakely, *Phys. Rev. Lett.*, **78** (1997), 3342.
126. M. G. R. Thomson, *J. Vac. Sci. Technol. B*, **12** (1994), 3498.
127. K. Thürmer, J. E. Reutt-Robey, E. D. Williams, *Surf. Sci.*, **537** (2003), 123.
128. J. K. Trolan, J. P. Barbour, E. E. Martin, W. P. Dyke, *Phys. Rev.*, **100** (1955), 1646.
129. D. W. Tuggle (PhD thesis, Oregon Graduate Center, 1984).
130. M. Uwaha, *J. Phys. Soc. Jpn.*, **57** (1988), 1681.
131. A. H. V. van Veen (M.Sc. thesis, Delft University of Technology, 2000).
132. A. H. V. van Veen, C. W. Hagen, J. E. Barth, P. Kruit, *J. Vac. Sci. Technol. B*, **19** (2001), 2038.
133. L. Vitos, A. V. Ruban, H. L. Skriver, J. Kollár, *Surf. Sci.*, **411** (1998), 186.
134. A. E. Vladár, Z. Radi, M. T. Postek, D. C. Joy, *Scanning*, **28** (2006), 133.
135. W. R. Wade, *NASA-Memo-1-20-59L* (1959).
136. K. Wang, R. R. Reeber, *Mater. Sci. Eng.*, **R23** (1998), 101.
137. J. W. Ward, R. L. Kubena, M. W. Utlaut, *J. Vac. Sci. Technol. B*, **6** (1988), 2090.
138. Y.-N. Wen, J.-M. Zhang, *Comput. Mater. Sci.*, **42** (2008), 281.
139. J. C. Wiesner, T. E. Everhart, *J. Appl. Phys.*, **44** (1973), 2140.

140. E. D. Williams, *Surf. Sci.*, **299/300** (1994), 502.
141. J. Worster, *Brit. J. Appl. Phys. (J. Phys. D)*, **2** (1969), 889.
142. W. Xu, J. B. Adams, T. L. Einstein, *Phys. Rev. B*, **54** (1994), 2910.
143. R. Young, S. Henstra, J. Chmelik, T. Dingle, A. Mangnus, G. van Veen, I. Gestmann, *Proc. SPIE*, **7378** (2009), 737803.
144. J.-M. Zhang, F. Ma, K.-W. Xu, *Surf. Interface. Anal.*, **35** (2003), 662.
145. Y. Zhang, P. Kruit, *J. Vac. Sci. Technol. B*, **25** (2007), 2239.
146. T. M. Gardiner, H. M. Kramer, E. Bauer, *Surf. Sci*., **112** (1981) 181.

List of publications associated with this work:

- M. S. Bronsgeest, P. Kruit, *J. Vac. Sci. Technol. B*, **24** (2006), 887: "Temperature dependence of the work function of the Zr/O/W (100), Schottky electron source in typical operating conditions and its effect on beam brightness" (Section 3.5.1 of this book).
- M. S. Bronsgeest, J. E. Barth, G. A. Schwind, L. W. Swanson, P. Kruit, *J. Vac. Sci. Technol. B*, **25** (2007), 2049: "Extracting the Boersch effect contribution from experimental energy spread measurements for Schottky electron emitters" (Section 4.4.2 of this book).
- M. S. Bronsgeest, J. E. Barth, L. W. Swanson, P. Kruit, *J. Vac. Sci. Technol. B*, **26** (2008), 949: "Probe current, probe size, and the practical brightness for probe forming systems" (Section 4.2 of this book).
- M. S. Bronsgeest, P. Kruit, *J. Vac. Sci. Technol. B*, **26** (2008), 2073: "Effect of the electric field on the form stability of a Schottky electron emitter: a step model" (Section 5.5.1 of this book).
- M. S. Bronsgeest, P. Kruit, *J. Vac. Sci. Technol. B*, **27** (2009), 2524: "Reversible shape changes of the end facet on Schottky electron emitters" (Sections 5.4.2 and 5.6.1 of this book).
- M. S. Bronsgeest, P. Kruit, *Ultramicroscopy*, **110** (2010), 1243: "'Collapsing rings' on Schottky electron emitters" (Sections 5.5.2–5.6.2 of this book).

Index