E-Beam Evaporation of SiO_2 for LCoS Alignment Layers

Source, power and crucible models from estimates of the SpatiaLight carousel coater

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1. Summary

This note documents four Python programs in `C:\LCoS\LCoS_Simulations\e-beam_evaporation` and their output. Together they connect three things for silicon dioxide (SiO_2) evaporated from an electron-beam gun: the source temperature and erosion, the beam power and current needed to hold that temperature, and the film growth rate on a 300 mm wafer in the SpatiaLight carousel coater, where the vapor arrives at about 82° from the wafer normal. That oblique-angle (glancing-angle, GLAD) deposition is what produces the tilted SiO_2 columns used as the liquid-crystal alignment layer in LCoS devices, and these models supply the input flux for the GLAD Monte Carlo simulations.

Main results with the default parameters (all values from the scripts as run on October 31, 2026):

- **Chamber geometry.** The source-to-wafer throw is 1.07 m and the vapor incidence is 82.2° at the wafer center (81.0° at the bottom edge, 83.2° at the top). Only 1.50×10^{-5} m/s of film grows per kg/s evaporated, so the carousel captures very little of the vapor.

- **Uniformity.** Across one wafer the growth rate varies 0.68 : 1 : 1.54 (top : center : bottom), and the in-plane vapor direction swings ±8.0°. Carousel rotation does not average this out, because the source sits on the rotation axis.
- **Required source temperature.** With the vapor-pressure data in the model, a uniformly heated 50 mm ingot needs about 1698 K for 5 Å/s at the wafer center. A real swept or focused beam heats only part of the surface, so the peak temperature must reach about 1800–2070 K, depending on spot size.
- **Beam current.** At 10 kV, 1 Å/s at the wafer center needs about 14 mA (2 mm spot) to 80 mA (12 mm spot); 5 Å/s needs 37–127 mA. Above about 1850 K most of the absorbed power leaves as latent heat of evaporation.
- **Hole drilling.** A stationary 7 mm (1σ) beam at 1950 K peak drills a crater 14.5 mm deep in 60 s, half the ingot height. The beam must be swept.
- **Crucible size.** For a swept beam the current rises almost linearly with pocket size, from 18 mA (4 cc liner) to 66 mA (100 cc) at 1 Å/s. A fixed 3 mm spot needs about 20 mA in any liner.
- **Material use.** At 2 Å/s the source must evaporate about 13 mg/s. A 15 cc liner filled to 70 % holds about 7 g of SiO_2 granules, so it lasts roughly 9 minutes, or about 100 nm of dense film per charge. Long GLAD runs need a 40–100 cc pocket or several pockets.
- **Calibration.** The absolute temperatures and rates are uncertain by about an order of magnitude. Supplier data (Kurt J. Lesker: about 2 Å/s at about 1200 °C) imply much easier evaporation than the vapor-pressure fits used here. A quartz-crystal calibration of rate against emission current in the actual chamber is the first experiment to run.

2. Software and files

Program	What it does	Main outputs
`spatialight_chamber.py`	Chamber geometry estimated from photos; incidence angle, throw and deposition-rate factor at any point on a wafer; shared command-line options and file helpers	printed geometry table
`ebeam_evaporation_model.py`	Vapor pressure and Hertz–Knudsen–Langmuir flux of SiO_2; 2D ingot erosion (Algorithms 1 and 2 of the pseudocode); temperature sweep and setpoint for a target rate	`ebeam_run_SiO2.png`, `ebeam_T_sweep_SiO2.png`, three CSV files

Program	What it does	Main outputs
`ebeam_power_model.py`	Steady-state heat balance of the ingot in a water-cooled hearth; beam power and current for a given peak temperature and spot size	`ebeam_power_vs_T.png`, `ebeam_power_split.png`, `ebeam_T_field.png`, CSV
`ebeam_crucible_geometries.py`	Standard Poco/Entegris EB-series liner geometries; SiO_2 charge geometry; current needed for 1, 2 and 5 Å/s in each liner	`ebeam_crucible_current.png`, CSV

All outputs are written to the `ebeam_output` subfolder next to the scripts. Run commands used for this note:

```
python spatialight_chamber.py
python ebeam_evaporation_model.py --no-show
python ebeam_evaporation_model.py --no-show --profile gaussian --T 1950 --
Tbase 1300 --sigma-mm 7 --outdir gauss
python ebeam_power_model.py --no-show
python ebeam_crucible_geometries.py
```

The power model takes about 2 minutes and the crucible script about 40 seconds. The source documents in `Papers_and_Data` (Lesker SiO_2 FAQ, FABMATE and graphite crucible data, Luxel crucible data, Luxel vapor-pressure chart, crucible selection guides) supply the practical anchors in Section 8.

3. Chamber geometry and deposition rate

The SpatiaLight coater is a box coater with a carousel drum about 1.0–1.15 m across. The 300 mm wafers sit on panels around the drum facing the axis, and the electron-beam gun sits on the floor on (or near) the axis. Dimensions were estimated from photographs, using the 300 mm wafer opening as a scale:

Quantity	Value used	Range from photos
Axis to wafer center, R	0.50 m	0.45–0.55 m
Source to wafer-center height, H	0.95 m	0.80–1.10 m
Panel tilt, top outward, τ	20°	chosen to give the remembered incidence near 82°

Quantity	Value used	Range from photos
Throw $L = \sqrt{(R^2 + H^2)}$	1.07 m	0.92–1.23 m
Emission angle from the source normal, θ_e	27.8°	—

A point on the wafer at distance s along the wafer's own "up" direction and w sideways lies at P = (R + s sin τ, w, H + s cos τ), and the coated face points along $\hat{n}$ = (−cos τ, 0, sin τ). For a source emitting $\dot{m}$ kg/s with a $\cos^n$ distribution, the film thickness grows at

$$\dot{d} = \frac{n+1}{2\pi} \frac{\dot{m} \cos^n \theta_e \cos\alpha}{L^2 \rho_f p} \tag{3.1}$$

where α is the vapor incidence angle from the wafer normal, ρ_f = 2200 kg/m^3 the dense-film density and p the packing fraction (1 for a dense film; about 0.5–0.7 for a porous GLAD film, which raises the physical thickness by 1/p). The default is n = 1, an ideal cosine source.

Panel tilt τ	Incidence α at wafer center	Rate factor (m/s per kg/s)
0° (vertical panels)	62.2°	5.17×10^{-5}
10°	72.2°	3.39×10^{-5}
15°	77.2°	2.45×10^{-5}
20° (default)	**82.2°**	$\mathbf{1.50 \times 10^{-5}}$
23°	85.2°	9.22×10^{-6}

Table 3.1. Effect of panel tilt on incidence angle and deposition-rate factor (spatialight_chamber.py).

At the default tilt the incidence ranges from 81.0° at the bottom of the wafer to 83.2° at the top. Because cos α changes quickly near 82°, the growth rate varies in the ratio 0.68 : 1 : 1.54 from top to bottom, and the projected vapor direction (which sets the column and pretilt azimuth) turns by ±8.0° across the wafer width. All carousel positions see the same geometry because the source is on the axis, so rotation averages only the source's own azimuthal non-uniformity.

4. Vapor pressure and evaporation flux

The vapor pressure of SiO_2 is represented by two extended-Antoine (DIPPR-101) fits:

$$\ln P\,[\text{Pa}] = A + \frac{B}{T} + C \ln T + D\,T^E \tag{4.1}$$

Range (K)	A	B (K)	C	D	E
1273.15–1473.15	9.0978	-2.0027×10^4	0	0	0
1696–2503.2	179.79	−77 310	−17.657	3.2595×10^{-21}	6

Between 1473 and 1696 K there is no fit. The program bridges the gap by interpolating ln P linearly in 1/T between the two endpoints and flags any temperature that falls there.

The number of molecules leaving unit area per second is the Hertz–Knudsen–Langmuir flux

$$\Phi = \frac{\alpha_v P(T)}{\sqrt{2\pi m k_B T}} \tag{4.2}$$

with m the molecular mass and α_v the evaporation coefficient (1 for ideal evaporation; real oxides are often lower). The mass flux is J = Φm, the surface recession rate is J/ρ, and a uniformly heated ingot face of area A evaporates ṁ = JA.

T (K)	P (Pa)	Fit	Recession (μm/s)	ṁ, Ø 50 mm face (mg/s)	Wafer-center rate (Å/s)
1300	1.8×10^{-3}	low	7.8×10^{-4}	0.0034	5.0×10^{-4}
1400	5.5×10^{-3}	low	2.3×10^{-3}	0.0097	1.5×10^{-3}
1500	3.1×10^{-2}	gap	1.2×10^{-2}	0.053	8.0×10^{-3}
1600	1.0	gap	0.39	1.7	0.25
1700	21	high	7.9	34	5.1
1800	100	high	36	156	23
1900	384	high	136	586	88
2000	1250	high	432	1870	280

Table 4.1. Temperature sweep for a uniformly heated Ø 50 mm SiO_2 ingot face (ebeam_T_sweep_SiO2.csv). The target of 5 Å/s at the wafer center is reached at about 1698 K.

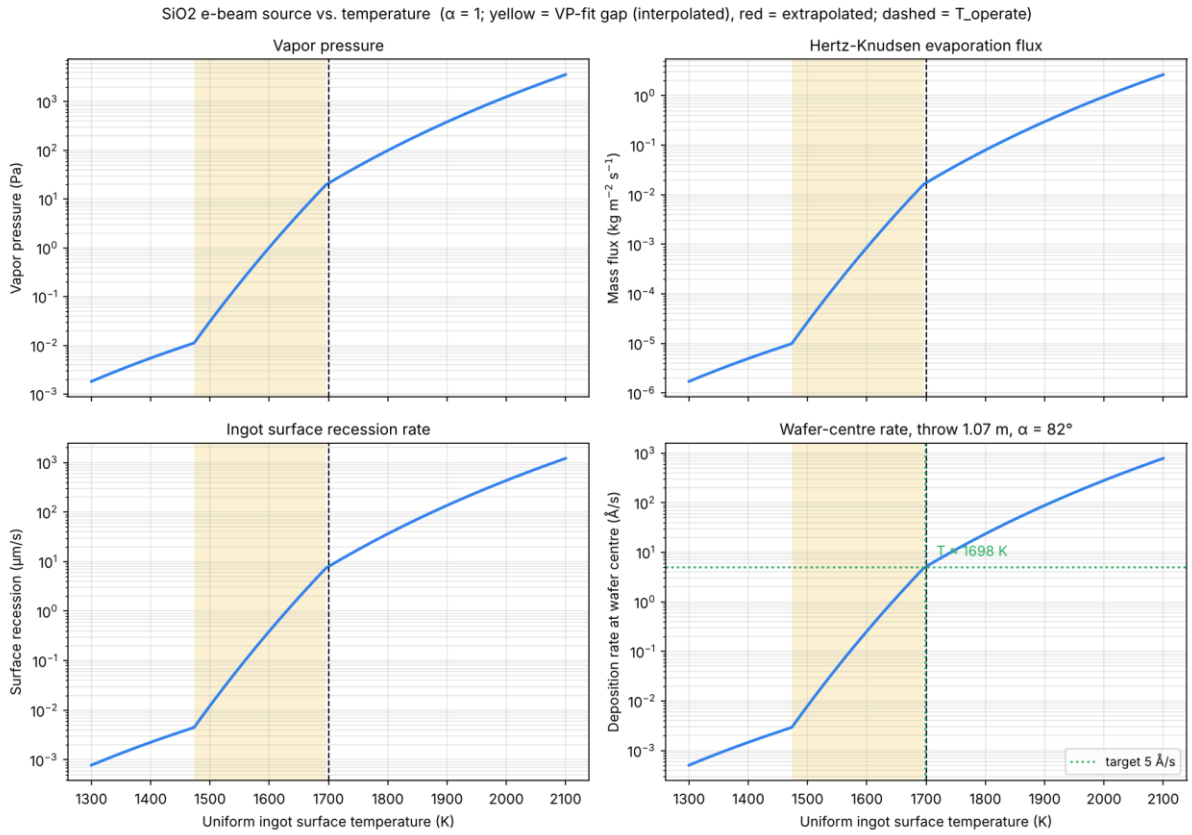


Figure 1. SiO_2 source properties against uniform surface temperature: vapor pressure, mass flux, surface recession and wafer-center deposition rate. Yellow shading marks the gap between the two vapor-pressure fits; the dashed line is the operating temperature (1700 K) and the green line the 5 Å/s target.

The two fits are not consistent with each other. The low-temperature fit has a slope equivalent to an enthalpy of vaporization of about 166 kJ/mol, the high-temperature fit about 400 kJ/mol near 1700 K, and the interpolated gap about 700 kJ/mol, so the pressure rises by a factor of about 1800 across the 220 K gap. The temperatures at which useful rates appear (1600–1700 K) fall in or next to this gap, so the setpoint temperatures in this note carry the largest uncertainty of any result. SiO_2 also evaporates mainly by decomposition ($SiO_2 \rightarrow SiO + ½O_2$), which the model treats as SiO_2 molecules leaving at the fitted total pressure.

5. Ingot erosion model

`ebeam_evaporation_model.py` divides a 2D slice through a Ø 50 × 30 mm ingot into a 50 × 50 grid (Algorithm 1 of the pseudocode), giving elements 0.6 mm deep and 1.0 mm wide that each hold 1.32×10^{19} molecules. In each time step t_p = 0.01 s, every surface column loses

$$\Delta N = \Phi\big(T(y)\big)\, A_e\, t_p, \qquad A_e = \Delta Y^2 \tag{5.1}$$

molecules, and any excess over the top element carries down to the next one (Algorithm 2). The script vectorizes this carry-over by tracking the cumulative removal in each column; mass is conserved to a relative error of about 10^{-15} in both runs below.

The current version corrects an error in the original notebook, which subtracted a mass flux in kg m^{-2} s^{-1} directly from element contents counted in molecules, with no area or time step. That removed about 68 “molecules” per step from elements holding about 10^{19}, so the ingot never visibly eroded.

Uniform 1700 K surface, 60 s. The whole face recedes evenly at 7.9 µm/s, reaching 0.47 mm in 60 s (1.6 % of the slice). The whole ingot evaporates 34.2 mg/s, giving 5.13 Å/s at the wafer center (3.50 Å/s at the top edge, 7.92 Å/s at the bottom).

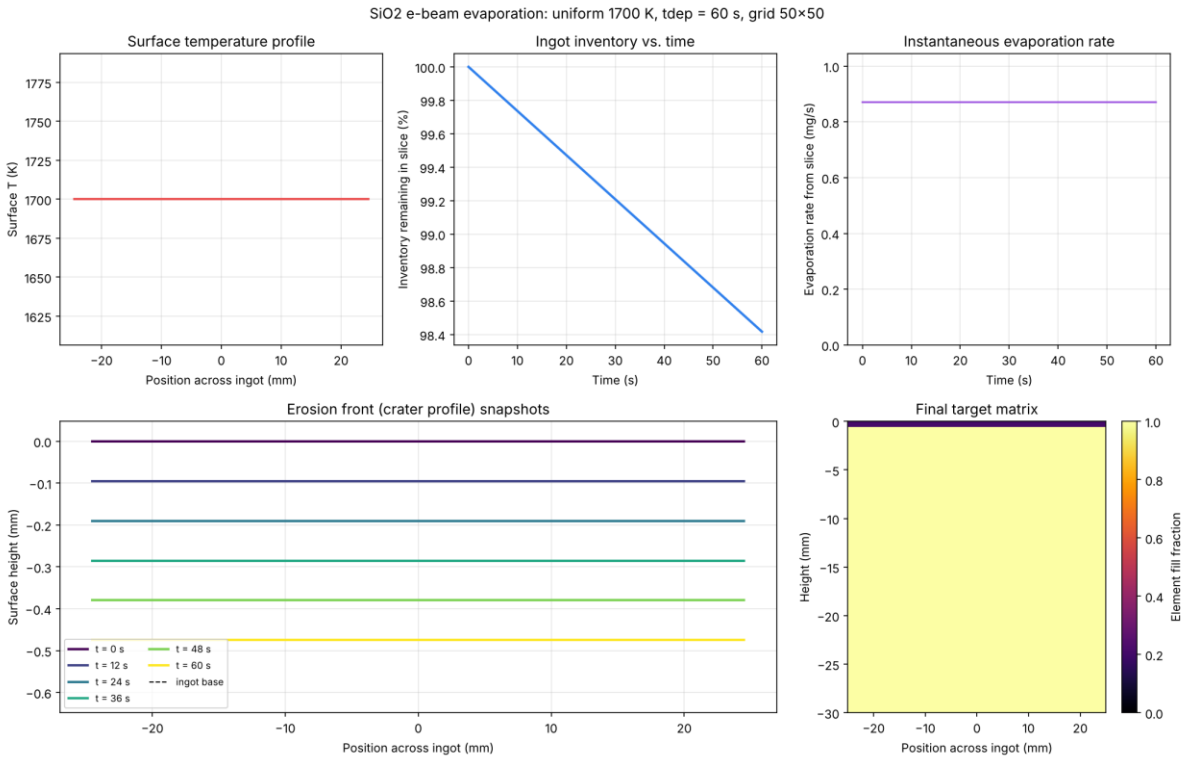


Figure 2. Uniform 1700 K surface for 60 s: temperature profile, inventory, evaporation rate, erosion-front snapshots and final element fill.

Stationary Gaussian hot spot, 1950 K peak, 1300 K edge, σ = 7 mm, 60 s. All the evaporation comes from the central 15 mm, which recedes at up to 242 µm/s. In 60 s the beam drills a crater 14.5 mm deep, half the ingot height, while the edges are untouched. The whole ingot evaporates 22.6 mg/s, giving 3.39 Å/s at the wafer center. This is the “hole drilling” that the Lesker guidance warns about: the beam must be swept, or the spot enlarged, to spread the erosion and keep it away from the liner bottom.

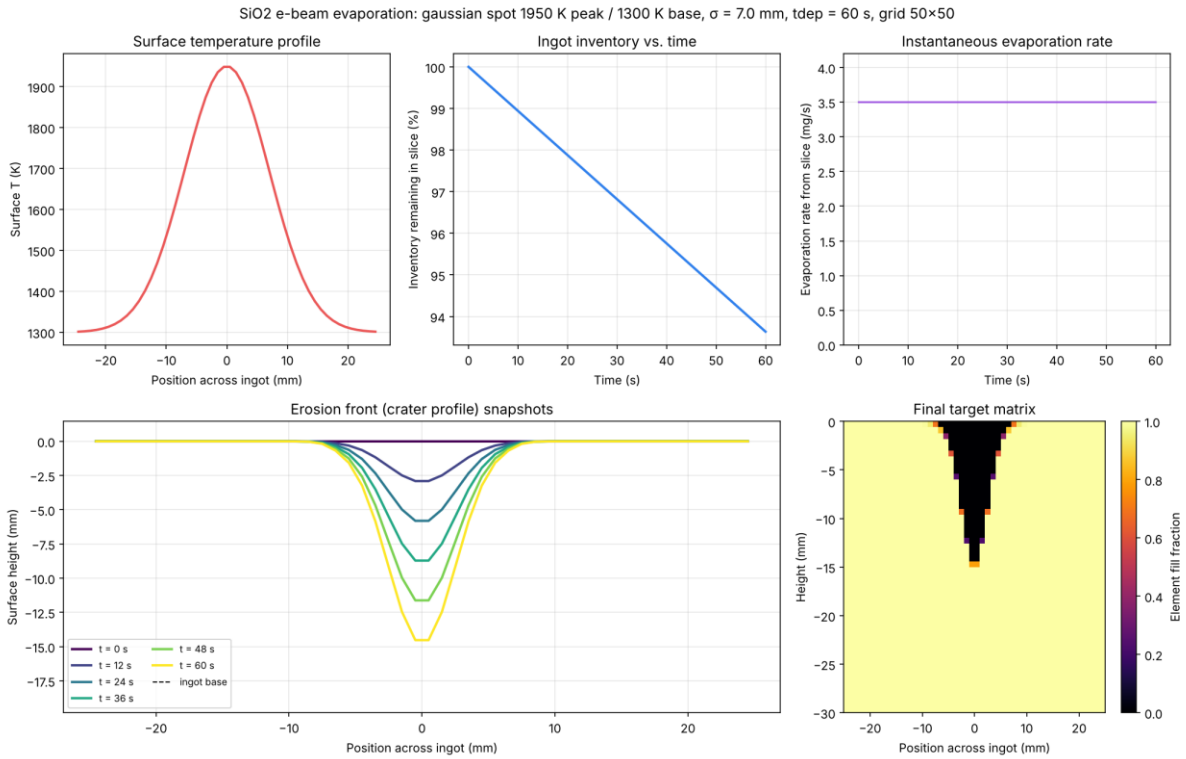


Figure 3. Stationary Gaussian spot (1950 K peak, σ = 7 mm) for 60 s: the crater reaches 14.5 mm, half the 30 mm ingot height.

(For this note the "instantaneous evaporation rate" panel was redrawn without matplotlib's offset notation. In the original script that panel shows a meaningless band for a constant rate; the change is two lines in `plot_run`.)

6. Beam power and current

`ebeam_power_model.py` solves the steady-state heat balance of the same Ø 50 × 30 mm ingot sitting in a water-cooled copper hearth:

$$\eta V I = P_{cond} + P_{rad} + P_{evap} \tag{6.1}$$

The beam deposits a Gaussian footprint of 1σ radius σ on the top surface; η = 0.9 of the beam power is absorbed (about 10 % is backscattered from a low-Z target). The top surface loses heat by radiation and evaporation,

$$q_{loss} = \varepsilon\,\sigma_{SB}(T^4 - T_{env}^4) + \frac{J(T)}{M}\,\Delta H_{vap}(T) \tag{6.2}$$

with ΔH_{vap} taken from the local slope of the vapor-pressure fits (Clausius–Clapeyron). The bottom and sides lose heat to the 300 K hearth through a contact conductance h_c. Inside, conduction with $k(T) = k_0 + k_1 T$ is made linear by the Kirchhoff transform $\theta = \int k\,dT$, which turns the interior equation into Laplace's equation for θ; the script solves it by finite volumes on a graded r–z grid (100 × 80) with an under-relaxed nonlinear iteration, then finds the power for each target peak temperature with a root finder.

Parameter	Value
Accelerating voltage V	10 kV
Absorbed fraction η	0.90
Emissivity ε	0.75
Contact conductance h_c	500 W m^{-2} K^{-1} (most uncertain: 100–500 for granules in a liner, ≳1000 for a fused starter slug)
Conductivity k(T)	1.0 + 1.3 × 10^{-3} T W m^{-1} K^{-1}
Spot sizes σ	2, 4, 7, 12 mm

Spot σ	1 Å/s	2 Å/s	5 Å/s
2 mm	1952 K, 14 mA (144 W)	1997 K, 21 mA (206 W)	2065 K, 37 mA (369 W)
4 mm	1863 K, 26 mA (255 W)	1900 K, 33 mA (332 W)	1955 K, 53 mA (529 W)
7 mm	1801 K, 45 mA (452 W)	1834 K, 56 mA (564 W)	1882 K, 82 mA (815 W)
12 mm	1752 K, 81 mA (805 W)	1782 K, 96 mA (956 W)	1824 K, 127 mA (1270 W)

Table 6.1. Peak surface temperature and emission current at 10 kV for a given wafer-center deposition rate in the SpatiaLight carousel (interpolated from ebeam_power_vs_T.csv).

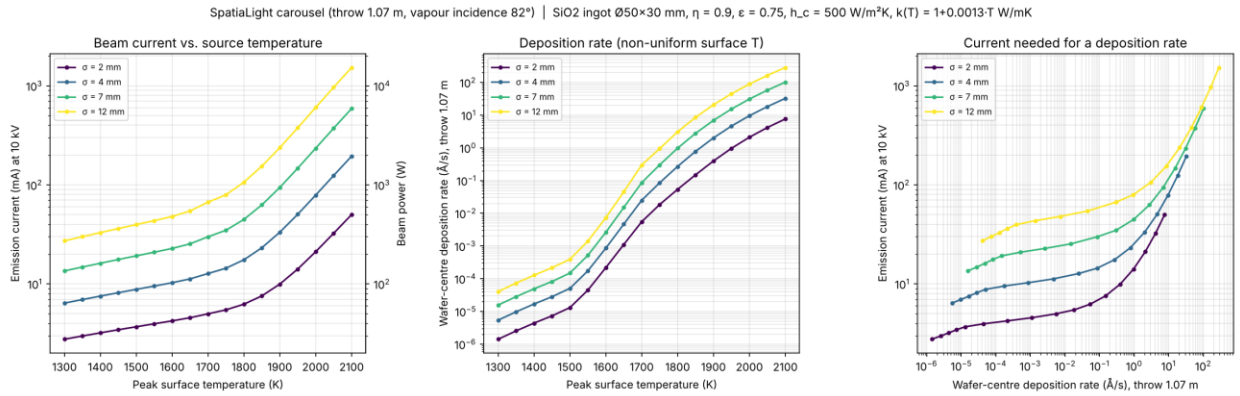


Figure 4. Emission current against peak temperature (left), deposition rate against peak temperature (center), and current against deposition rate (right) for four spot sizes.

A small spot reaches a given rate with the least power, but at a higher peak temperature and, from Section 5, with faster hole drilling. A large spot evaporates from a wider area at a lower temperature but needs several times the current. Below about 1700 K nearly all of the absorbed power is conducted into the hearth or radiated; above about 1850 K the latent heat of evaporation dominates, so power rises steeply with temperature (Figure 5). Figure 6 shows the temperature field for σ = 7 mm at 1600 K peak: the hot zone is a shallow cap a few millimeters deep, and most of the ingot stays below 800 K.

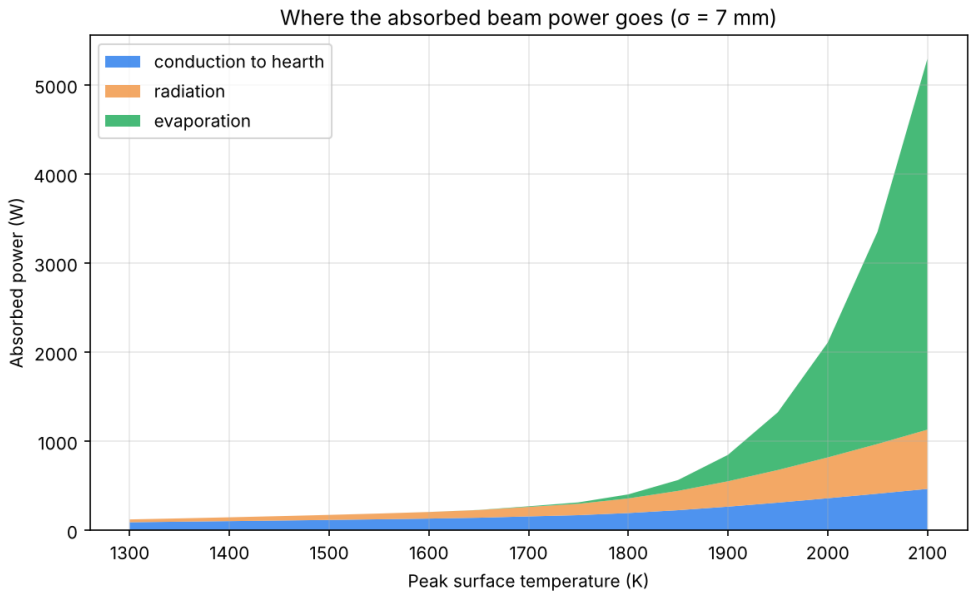


Figure 5. Where the absorbed power goes for σ = 7 mm: conduction to the hearth, radiation and evaporation.

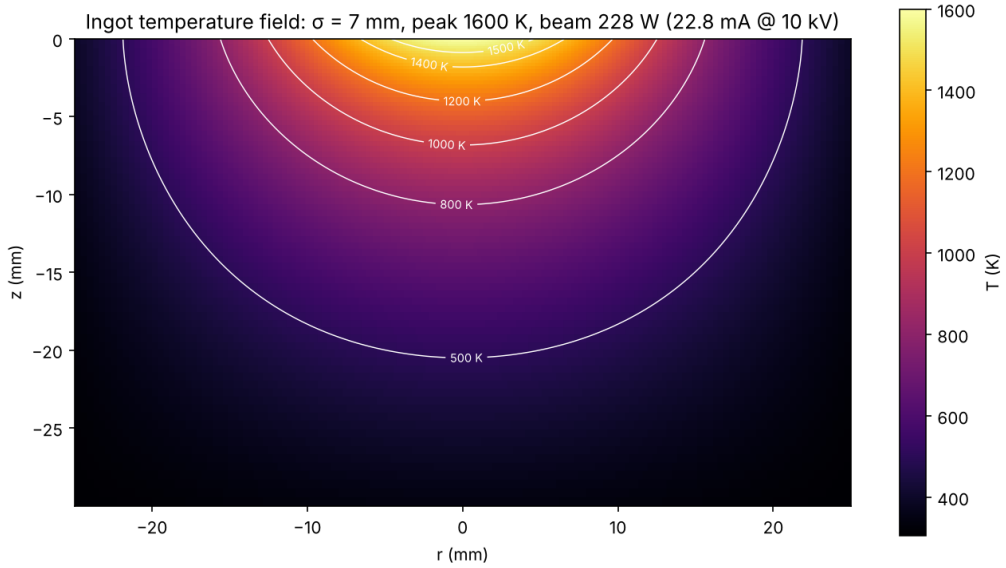


Figure 6. Steady temperature field in the ingot for σ = 7 mm and 1600 K peak (228 W, 22.8 mA at 10 kV).

The Gaussian run in Section 5 and the power model give different rates for the same peak temperature and σ (3.4 against 15 Å/s at 1950 K, σ = 7 mm). The difference is that the power model computes the surface temperature profile from heat spreading, which is wider than the assumed Gaussian with a 1300 K floor; the power model is the more physical of the two.

7. Crucible liners and charge size

`ebeam_crucible_geometries.py` takes seven standard 15°-tapered graphite liners from the Poco/Entegris EB-series and Neyco catalogs, fills each to 70 % of its inner depth (Lesker

recommends ⅔–¾), and represents the charge in the thermal model by a cylinder of the same volume and height. Granule packing is taken as 60 % of 2.2 g/cm³.

Liner	Pocket (cc)	Fits	Charge surface Ø (mm)	Fill height (mm)	Charge volume (cm³)	SiO_2 mass (g)
EB-22	4	Telemark 211-04, 261-14/44	15.7	8.9	1.26	1.7
EB-4	7	Temescal FIH/TIH/STIH-270, Telemark 271-5/6	23.0	8.4	2.84	3.7
EB-13	15	Temescal STIH-270-2, Gemini, Trigon; Telemark 211/261/271/272	29.0	9.7	5.32	7.0
EB-16	25	Telemark 271-03…08, 271-36/37; Temescal STIH-270-3/4	39.9	10.4	11.3	14.9
EB-8	40	Temescal FIH/SFIH/UHVC-270-2	42.1	17.2	19.1	25.3
EB-6	40	Telemark 272-04; Temescal FIH-270-2	43.1	16.5	19.4	25.6
EB-27	100	Telemark 272-05	58.2	24.8	52.0	68.7

Liner	Swept beam (σ = Ø/6): 1 / 2 / 5 Å/s (mA)	Tight 3 mm spot: 1 / 2 / 5 Å/s (mA)	Peak T, swept, 2 Å/s
EB-22	17.8 / 24.5 / 41.4	19.2 / 26.0 / 43.1	1960 K
EB-4	25.2 / 33.1 / 52.6	20.5 / 27.7 / 45.9	1909 K
EB-13	31.5 / 40.4 / 61.6	20.3 / 27.5 / 45.7	1880 K
EB-16	44.3 / 54.9 / 79.4	20.1 / 27.2 / 45.3	1842 K
EB-8	45.7 / 56.3 / 81.1	19.8 / 26.9 / 44.9	1835 K
EB-6	46.8 / 57.8 / 82.9	19.8 / 26.9 / 44.9	1833 K
EB-27	65.6 / 78.5 / 107.6	19.6 / 26.6 / 44.6	1800 K

Table 7.1. Emission current at 10 kV for 1, 2 and 5 Å/s at the wafer center, by liner (ebeam_crucible_geometries.csv).

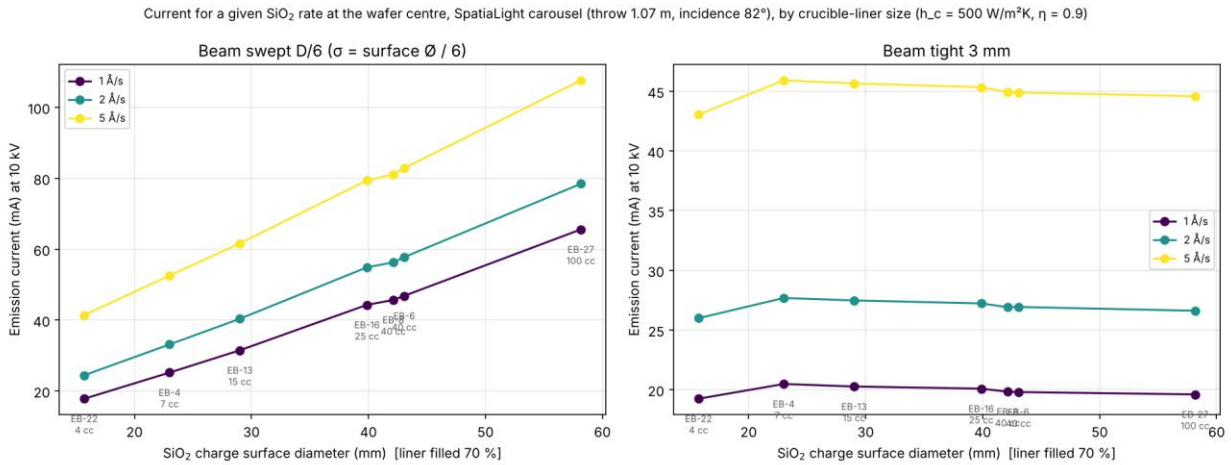


Figure 7. Emission current for 1, 2 and 5 Å/s against charge surface diameter, for a swept beam (σ = surface Ø/6) and a fixed 3 mm spot.

With a swept beam the current grows almost linearly with charge diameter, because the heated area grows. With a fixed 3 mm spot the current is nearly independent of liner size (about 20, 27 and 45 mA for 1, 2 and 5 Å/s), since only the spot region evaporates.

Material consumption. From Equation 3.1, 2 Å/s at the wafer center needs $\dot{m} \approx 13$ mg/s. That empties the 7.0 g charge of an EB-13 liner in about 9 minutes (about 105 nm of dense film), and only part of it is usable, because the beam should not run below about 30 % fill. The 100 cc EB-27 liner (68.7 g) lasts about 85 minutes. For GLAD layers of a few hundred nanometers, especially with a porous film ($p \approx 0.5$–0.7, so more physical thickness per gram), a 40–100 cc pocket, a multi-pocket rotation or a fused starter slug is needed.

8. Comparison with practical data and calibration

The models have not yet been calibrated against the SpatiaLight tool. The practical sources in `Papers_and_Data` and two anchors noted in the scripts give the following comparisons.

Source	Statement	Model comparison
Kurt J. Lesker FAQ (SiO_2)	About 2 Å/s at an "evaporation temperature" of about 1200 °C (1473 K); substrate 350 °C; O_2 partial pressure 1×10^{-5} Torr (1.3×10^{-3} Pa); fill liner ⅔–¾; sweep at low power to fuse the surface and avoid hole drilling; replace dark material	For a uniformly heated Ø 50 mm face at 1473 K the model gives about 0.004 Å/s in the SpatiaLight carousel, and only about 0.1 Å/s even at a normal-incidence geometry that collects about 30 times more vapor. Reaching 2 Å/s in the carousel takes about 1670 K uniform, or 1780–2000 K peak. Either the vapor-pressure fits are too low by a factor of 20 or more at 1473 K, or the quoted temperature is a reading of a region cooler than the evaporating spot.

Source	Statement	Model comparison
Luxel vapor-pressure chart (SiO)	SiO reaches 0.13 Pa (10^{-3} Torr) at about 950 °C and 1.3 Pa at 1028 °C	The SiO_2 fits reach 1.3 Pa only near 1610 K (1337 °C). The SiO_2 vapor is mostly SiO + O_2, so the SiO curve is a closer guide to the real volatility.
DTU Nanolab Temescal-2 (recorded in `ebeam_power_model.py`)	SiO_2 at about 1 Å/s with about 170–280 W	In an EB-13 (15 cc) liner the model needs 200–315 W for 1 Å/s in the SpatiaLight geometry. The DTU tool deposits at normal incidence on a different throw, which collects about 20–40 times more vapor per gram (for a 0.5–0.7 m throw) than the 82° carousel, so at its geometry the model would predict a much higher rate for the same power. The throw of the DTU tool is not recorded, so this comparison is qualitative.
Lesker FABMATE crucible notes	Two ramp/soak power levels; set the second soak close to the power for the target rate so the rate-control loop makes only small changes; avoid abrupt power shut-off	Table 7.1 gives a starting estimate for the soak-2 current in each liner.

The supplier data point in opposite directions: they imply that SiO_2 evaporates at a lower temperature than the fits predict, while the DTU power anchor suggests less vapor per watt than the model gives. The absolute temperatures and currents in this note should therefore be treated as uncertain by about a factor of ten. The trends are robust: dependence on spot size and liner size, the steep onset of evaporation heat loss, hole drilling with a stationary beam, the geometric collection factor and the across-wafer non-uniformity.

Recommended calibration. Place a quartz-crystal monitor at a wafer position (or measure film thickness on a test wafer by ellipsometry) and record deposition rate against emission current for two or three sweep patterns in the liner that will be used. Fitting the model's evaporation coefficient α_v (or a temperature offset of the vapor-pressure curve) and the contact conductance h_c to those points will bring the current and setpoint predictions into line with the tool.

9. Implications for the SpatiaLight GLAD process

1. **Sweep the beam and start with a fused surface.** A stationary spot drills half-way through a 30 mm charge in a minute. Use a low-power sweep to fuse the granules first, as Lesker recommends, then a sweep pattern covering about two thirds of the charge surface ($\sigma \approx$ Ø/6, as in Table 7.1).

2. **Choose a large pocket.** At 82° incidence and 1.07 m throw, the source must evaporate about 13 mg/s for 2 Å/s, so small liners run out within minutes. An EB-8/EB-6 (40 cc) or EB-27 (100 cc) liner, or a starter slug in the hearth, is the practical choice.
3. **Expect about 20–80 mA at 10 kV for 1–2 Å/s,** depending on liner and sweep (Table 7.1), before calibration. Set the second soak level close to this to avoid power oscillation and crucible cracking.
4. **Wafer non-uniformity is set by geometry.** The 0.68 : 1.54 top-to-bottom rate ratio and the ±8° change in vapor azimuth across a 300 mm wafer will appear as variations in alignment-layer thickness and pretilt direction. Masks, a smaller panel tilt, or using only the central part of the wafer for LCoS dies can reduce this; the GLAD Monte Carlo should be run at the top, center and bottom incidence angles (83.2°, 82.2°, 81.0°).
5. **Feed the GLAD Monte Carlo.** The rate and incidence angles from Sections 3 and 6 are the flux inputs for `oad_sio2_montecarlo*.py`. Run it with the packing fraction from the Monte Carlo fed back into Equation 3.1, so that physical thickness and deposition time agree.

10. Limitations

- The vapor-pressure fits disagree with each other and with supplier data (Sections 4 and 8); SiO_2 is treated as evaporating as molecules rather than as $SiO + O_2$.
- The source is a point $\cos^n$ emitter with sticking coefficient 1; vapor-cloud effects, background-gas scattering at 10^{-3} Pa O_2 and reflection from the 82° surface are ignored.
- The thermal model is steady-state and axisymmetric; a swept beam is represented by its time-averaged Gaussian footprint, and crater formation does not feed back into the heat balance.
- Chamber dimensions come from photographs, with an uncertainty of about ±10 % in R and H and a tilt chosen to match a remembered incidence angle.
- The contact conductance h_c, emissivity and absorbed fraction η are estimates; h_c in particular varies by a factor of ten between loose granules and a fused slug.

References

1. Kurt J. Lesker Company, “Frequently Asked Questions: How do I e-beam evaporate silicon dioxide?”, https://www.lesker.com/newweb/faqs/question.cfm?id=349 (accessed October 16, 2026; copy in `Papers_and_Data`).
2. Kurt J. Lesker Company, “FABMATE® Crucibles for E-Beam Sources”, https://www.lesker.com/newweb/evaporation_sources/e-beam-crucibles-fabmate.cfm (copy in `Papers_and_Data`).
3. Luxel Corporation, “Evaporative Crucibles and Liners” and “Vapor Pressure Chart” (copies in `Papers_and_Data`).
4. Entegris/Poco Graphite, EB-series crucible liner datasheet 7087; Neyco crucible liner catalog (dimensions in `ebeam_crucible_geometries.py`).

5. “Crucible Selection Guide” and “Recommended Crucibles for Evaporation Materials” (copies in `Papers_and_Data`).
6. DTU Nanolab, Temescal-2 e-beam evaporator process data for SiO_2 (as recorded in `ebeam_power_model.py`).
7. “Pseudo-Code for E-Beam Evaporation of Oxides” and `EBeam_Evaporation_Model.nb`, LCoS Simulations folder (Algorithms 1 and 2).