

# List of Symbols

$a$	Specific evaporation rate
$a_u$	Born radius (0.529 Å)
$A$	An individual atom
$A_2$	Two atom cluster
$A_3$	Three body cluster
$A_n$	Cluster containing n atoms
$A_{n-1}$	Cluster containing n-1 atoms
$A_{pipe}$	Area of the inlet flow tube
$b$	Impact parameter
$b_{max}$	Maximum range of interaction of atoms involved in a collision event
$B$	Beam energy
$B_o$	Initial beam energy
$c$	Speed
$\bar{c}$	Average speed
$[Cu]$	Concentration of metal monomer
$[Cu_2^*]$	Concentration of unstable dimers
$d$	Diameter
$d_s$	Local film thickness on a flat substrate
$d_{so}$	Maximum film thickness
$D$	Distance
$e$	Binary collision encounters
$e$	Charge on an electron
$E$	Kinetic energy
$f$	Velocity distribution function
$F$	External force
$h$	Thickness

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$h_v$	Source to substrate separation distance
$H$	Total Enthalpy
$\Delta H$	Enthalpy
$[He]$	Concentration of background gas
$I$	Intensity
$I$	Beam current
$I_o$	Initial intensity
$k$	Boltzmann's constant ( $1.381 \times 10^{-23}$ J/K)
$Kn$	Knudsen number
$l$	Atomic jump distance on crystal surface
$L$	Characteristic dimension of a modeled volume
$n$	Exponent in vapor density distribution function
$n$	Gas atom number density
$n$	Number of jumps
$N$	Number of molecules in an ensemble
$m$	Mass
$m_c$	Carrier gas atom mass
$m_v$	Vapor atom mass
$M$	Three-body collision partner
$M$	Mach number
$M^*$	Energized third member of cluster collision event
$\mathbf{n}_o$	Direction unit vector
$N_A$	Avogadro's number ( $6.0221 \times 10^{23}$ atoms/mol)
$N_{av}$	Average size of clusters
$P$	Pressure
$P_c$	Carrier gas pressure
$P_{collision}$	Probability of a collision
$P_d$	Downstream pressure at a nozzle or inside a processing chamber
$P_o$	Upstream pressure before a nozzle

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$P_s$	Saturated vapor pressure
$\mathbf{q}$	Direction vector
$q$	Heat flux
$r$	Distance between atoms
$r_{min}$	Distance of closest interatomic approach
$r_e$	Evaporation rate
$r_s$	Distance from midpoint of substrate
$R$	Universal gas constant (8.314 J/(mol K))
$R_e$	Electron range
$R_s$	Specific gas constant
$s$	Direction vector
$t$	Time
$T$	Absolute temperature
$T_c$	Carrier gas temperature
$T_d$	Downstream temperature
$T_o$	Upstream temperature
$T_v$	Absolute temperature of an evaporant
$u$	Speed in first coordinate direction
$\bar{u}$	Average speed in first coordinate direction
$u_i$	Velocity
$U$	Speed of carrier gas stream
$U_{  }$	Carrier gas velocity parallel to primary flow
$U_{\perp}$	Carrier gas velocity perpendicular to primary flow
$U_c$	Velocity of carrier gas stream
$U_{ccm}$	Velocity of carrier gas atom in center-of-mass system prior to collision
$U_v$	Velocity of vapor atom
$U_{vcm}$	Velocity of vapor atom in center-of-mass system prior to collision
$U_{pipe}$	Speed of carrier gas through inlet flow tube
$\dot{U}_{pipe}$	Pumping capacity

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$\dot{U}_{pump}$	Pumping capacity
$v$	Speed in second coordinate direction
$\bar{v}$	Average speed in second coordinate direction
$V$	Volume
$V$	Molar density of material
$V(r)$	Interatomic potential
$w$	Speed in third coordinate direction
$\bar{w}$	Average speed in third coordinate direction
$W$	Molecular weight of an evaporant
$W$	Power
$x$	Collision
$x$	Position
$x_m$	Mach disk distance from nozzle exit
$z$	Third coordinate axis
$Z_A$	Atomic number of carrier gas
$Z_B$	Atomic number of vapor atom
$Z_{Cu2-He}$	Volume collision frequency
$\chi$	Center of mass scattering angle
$\chi_{cutoff}$	Minimum angle used during scattering calculations
$\varepsilon$	Efficiency of energy utilization
$\gamma$	Ratio of specific heats ( $c_p/c_v$ )
$\lambda$	Mean free path
$\lambda_e$	Effective mean free path
$\theta$	Angle
$\phi$	Magnitude of normal distribution for specific value of $U_c$
$\rho$	Density
$\rho_o$	Settling chamber gas density
$\sigma_{ji}$	Viscous stress tensor
$\sigma(\chi)$	Angular differential cross-section

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$\sigma_{aCu}$	Activity radius of a copper atom
$\sigma_{aCu2}$	Activity radius of an unstable dimer
$\sigma_d$	Directed momentum transfer cross-section
$\sigma_{rCu}$	Hard sphere radius of a copper atom
$\sigma_{rHe}$	Hard sphere radius of a helium atom
$\tau$	Time of flight
$\mu$	Reduced mass of a collision event
$\mu/\rho$	Mass absorption coefficient
$\xi$	Standard deviation