Principles of Electrostatic Chucks

6 — Rf Chuck Edge Design

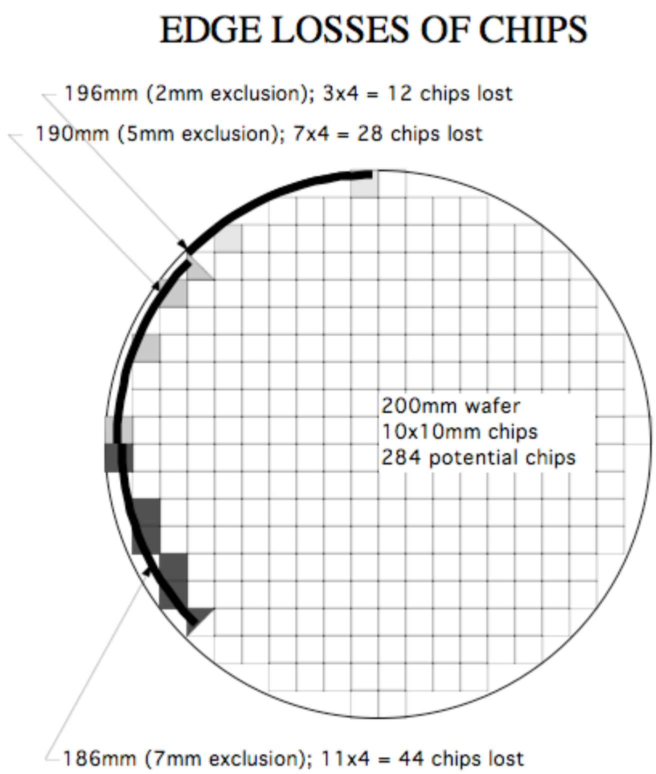
Overview

This document addresses the following chuck edge design issues:

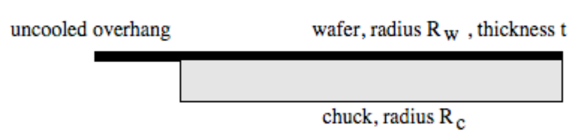
- Device yield through system uniformity and particle reduction;
- System maintenance through edge cleanability and wafer retention;
- Plasma - chuck electrical interactions due to chuck electrode design.

Edge Yield

- 100mm^2 chips on a 200mm dia. substrate are assumed here.
- For 1 wafer processed every 2 minutes, and for chips worth $20, the edge exclusion hourly losses are:
  - $7,200 for a 2mm exclusion;
  - $16,800 for a 5mm exclusion;
  - $26,400 for a 7mm exclusion.
- Attaining edge yield requires that all processing machines allow processing to the edge,
from resist spinning edge bead to plasma machines to furnace supports.



Overhang Thermal Effects



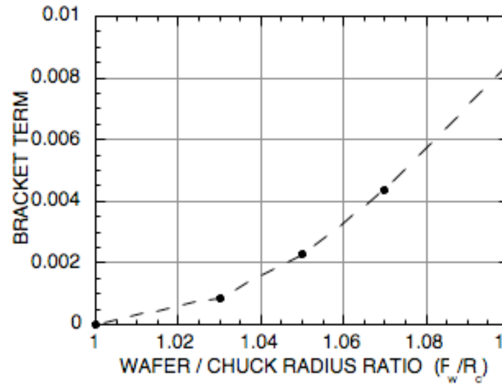
- Assume a wafer exposed to a uniform plasma heat source of power P to wafer.
- Vertical heat conduction through wafer to chuck over chuck surface, except at edge.
- At the edge cooling is poorer and lateral heat flow through the wafer occurs, with consequent higher edge temperatures.
- High edge temperatures result in altered deposition conditions and wafer hoop stress.
- An idealised calculation is shown below.

Assume no radiative loss (all heat is sunk to chuck).

For T_W = wafer edge temperature and T_C = wafer temp. over chuck:

$$T_W - T_C = \frac{P}{4 \pi \kappa t} \left\{ \ln (R_W / R_C) - 0.5 + R_C^2 / (2 R_W^2) \right\}$$

where P = total power to wafer and κ is the wafer thermal conductivity. The curly-bracketed term is shown graphically to the right.

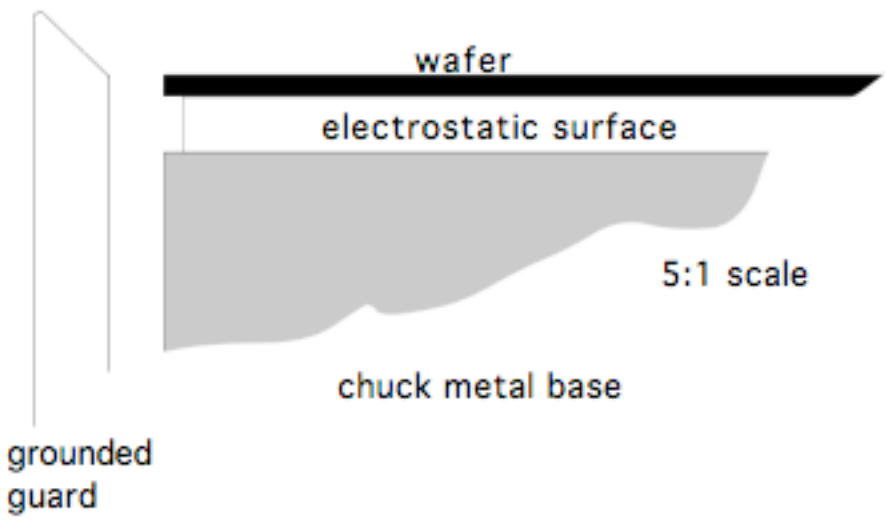


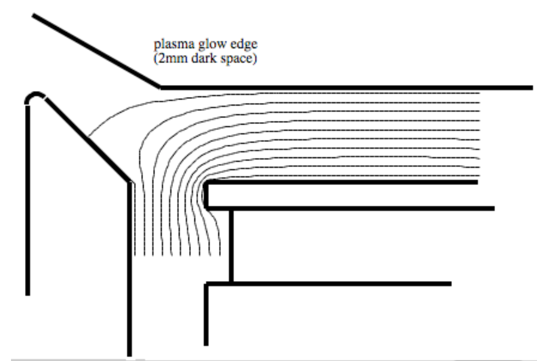
The ratio in front of the curly bracket, for Si with κ = 100 W/(m-K) and t = 0.5mm, is ~3 P (W).

For 150mm wafers with 140mm chuck dia. the radius ratio R_W/R_C is 1.07; and for 200mm wafers with 190mm chuck dia. it is 1.05.

Typical values for 5mm overhang:
P=100W, ΔT=1°C
P=1kW, ΔT=10°C.

SIMPLE OVERHANG CHUCK



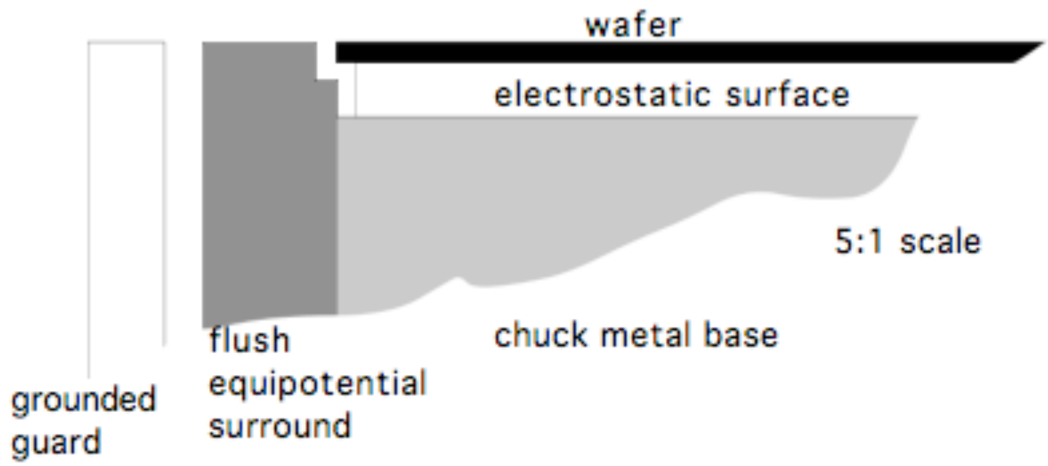


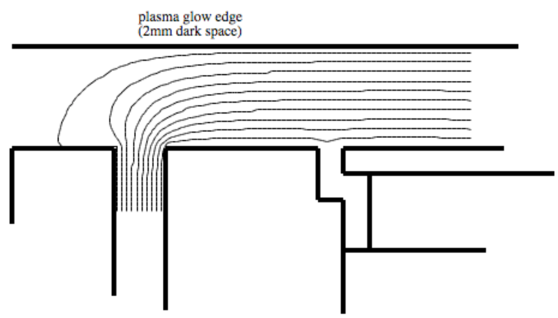
<u>Field plot</u> (-200V bias on wafer, +20V plasma potential with respect to grounded guard)
• ions, mainly from the glow edge at low pressures, are accelerated normal to field lines. Thus ions start at glow edge and generally bombard normal to the wafer surface.

<u>Wafer retention</u>
• Guard ring retains wafer in case of slippage from chuck surface.

<u>Plasma effects</u>
• Edge of wafer is more heavily ion-bombarded than center due to ion lensing. Plasma extends around edge; may etch / coat on wafer edge and underside, and chuck side.
• Cleaning: chuck minimally; guard regularly to minimise particles in deposition processes.

FLUSH CONSUMABLE RING



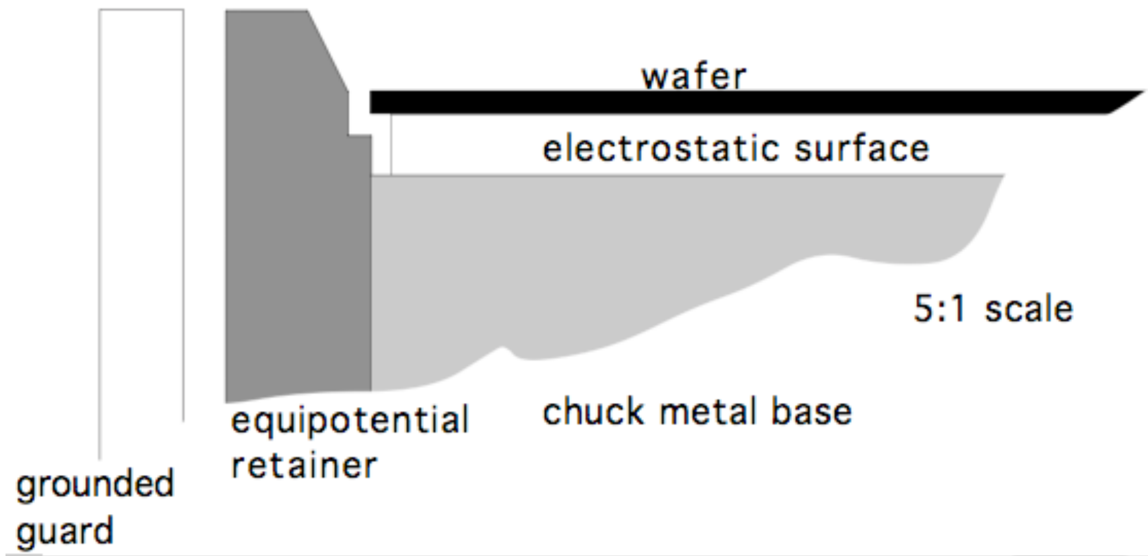


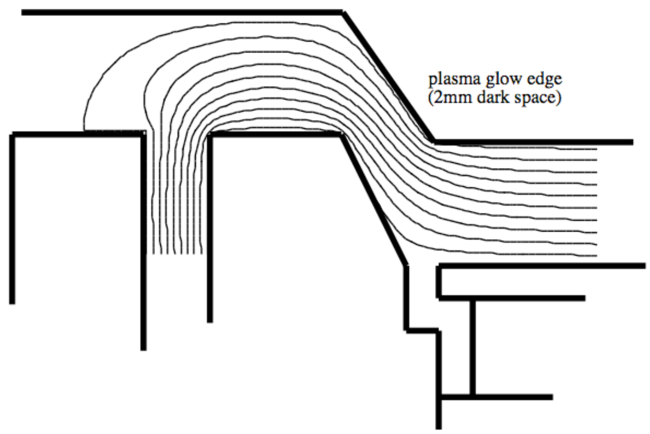
Field plot (-200V bias on wafer, +20V plasma potential with respect to grounded guard)
• ions, mainly from the glow edge at low pressures, are accelerated normal to field lines.
The dark space in these diagrams is the ion acceleration space between plasma and wafer.

Wafer retention
• Recess in surround ring retains wafer by thickness of wafer only. Guard ring, if raised in height, could retain wafer in case of slippage from chuck surface.

Plasma effects
• Very uniform wafer ion bombardment if surround ring rf impedance is matched to chuck.
• Cleaning: Chuck minimally; Guard and surround ring regularly to minimise particle generation in deposition processes.
• Replace surround ring when etched below wafer thickness mid-point. Surround ring etch products contribute to etch process chemistries.

RETAINER RING





Field plot (-200V bias on wafer, +20V plasma potential with respect to grounded guard)
• ions, mainly from the glow edge at low pressures, are accelerated normal to the field lines.

Wafer retention
• Retainer ring retains wafer in case of slippage from chuck surface.

Plasma effects
• Lighter wafer ion bombardment at edge compared to center due to ion lensing. Plasma may etch or coat on retaining ring. Plasma particle trap inside ring possible.
• Chuck surface is not consumable. Chuck requires little if any cleaning. Clean the retaining ring to minimise particle generation in deposition processes.
• Replace retaining ring when severely etched. Retaining ring etch products contribute to etch process chemistries.

PLASMA-CHUCK ELECTRICAL INTERACTIONS

• Rf *plasma contact induces bias* A surface in contact with plasma and capacitively coupled to outside rf circuitry (such as an rf sputtering target or chamber wall) will equilibrate to a negative voltage with respect to the plasma. Plasma electrons have lower mass and higher velocity than plasma ions. Thus electrons can arrive in a short high-current pulse with a total charge equal to that of the lower peak ion current, which is averaged over the full rf cycle. For the smaller electrode, the average negative voltage with respect to the plasma (typically comparable with the "rf bias voltage" in an asymmetric area-ratio system) is raised to about half of the rf peak-to-peak voltage. For the peak time of each positive half cycle, electrons are pulled quickly to the surface and fully discharge the surface. When the rf voltage goes negative, electrons are repelled. Ions arrive (more slowly) resulting in zero overall charge transfer.

• *Rf plasmas use high currents* Typical substrate currents in high density plasmas are of the order of amperes for 200mm dia. susbtrates. Low density, low pressure "RIE" plasmas still reach 100mA current levels. These currents can easily be verified by shorting a conducting target's induced dc bias to ground through a current meter. The induced plasma bias on targets is typically between 100V and 1kV, yielding a "resistance" to dc current flow on 200mm substrates of the order of 500V / 1A = 500Ω.

• *Plasma edge conduction* At target edges there is reduced plasma penetration through small gaps (typically 1mm wide and 2mm deep) to underlying target metal electrodes, at least at low plasma pressures. If metal contact area is further reduced for low plasma contamination, plasma bias source resistance can reach many megohms, requiring a high impedance bias sense circuit. Electrogrip DR4 drivers typically have a 68MW bias sense impedance. This impedance can be increased if desired. The bias monitoring impedance in the Electrogrip DR6VI is approx. 2GΩ, which permits accurate readings in the presence of high plasma source resistance.

• *Electrostatics use low currents and are limited for safety* Typical electrostatic gripping power supplies deliver 700V through 1MΩ resistance to anodised Al grip electrodes, and 4kV through 20MΩ resistance to higher-resistance dielectrics such as those used by Electrogrip. Hence available current levels are lower than 1mA and, combined with the low system capacitance, are ‘touch safe’ against lethal shocks, though not against shock-induced rapid motions.

• *Electrode contact with plasma* If the conductive plasma contacts one of the gripping electrodes then grip forces and the plasma will be affected. The same negative bias will be induced on both gripping electrode and substrate, yielding a low grip force.

• *Avoidance of electrode contact* Isolation of gripping electrodes from plasma is generally preferred. Such designs may be monopolar, bipolar, tripolar, etc. , and use gripping electrodes which are embedded in insulator on all sides or protected from plasma with a metal shield electrode.

• *Electrode contact can sometimes be good* In tripolar chuck designs using floating gripper power supplies, the third tripolar electrode must contact plasma to provide a bias voltage reference for the gripping power supply. Electrogrip ‘bipolar’ rf chucks are really tripolar, with two gripping electrodes embedded inside insulator and totally inaccessible to the plasma. The third electrode is a metal shield, additionally blocking plasma from the gripping electrodes. Plasma contact to the baseplate electrode yields an rf bias voltage which is isolated in the DR6VI and DR5VI or filtered in the BD3 bias decoupler and then fed on the high voltage cable shields to a DR4 driver. Either way, the gripping electrode potentials are referenced to the true instantaneous rf substrate potential, for a constant gripping force independent of rf plasma voltage.

CHUCK EDGE DESIGN CHOICES

TYPE OF EDGE: PROPERTY	Edge Overhang	Flush Surround	Retaining Ring
Ion bombardment unif.	Poor (high at edge)	Excellent	Poor (low @ edge)
Temperature unif.	Poor (high at edge)	Good (high at edge)	Excellent
Chuck edge bombard	Low	Low-zero	Low-zero
Edge material bombard	Low	High	High
Deposition:			
Clean frequency	Low	Med	High
Cleaned parts	Guard	Guard, Ring	Guard, Ring
Lateral wafer retention	Good	Poor	Good
Synchronised wafer lift	Required	Not required	Not required

SUMMARY

Edge Uniformity, Process Cleanliness
There is no universal "best" solution to the edge uniformity / process cleanliness tradeoff. Chuck edge design is determined by accessibility for maintenance and the process.

Examples:
• an inaccessible chamber used for deposition would favour edge overhang;
• an accessible chamber used for etch processes would favour flush surround ring;
• where wafers are likely to slip off the chuck surface due to vibration or process irregularities, the edge overhang or retaining ring designs are preferred;
• if wafer lift timing is not well synchronised with grip and release timing, in the edge overhang design wafers may slip and short against the guard ring.

Electrogrip chucks can be made in all of the varieties shown.

Plasma Contact to Gripping Electrodes
Plasma contact to the gripping electrodes must be avoided. However in tripolar designs plasma contact to the third baseplate electrode is required for correct operation.

Electrogrip provides integrated systems of chucks, bias decoupler filters, and floating high voltage drivers. These systems yield a grip force independent of plasma parameters. Electrogrip systems have no plasma degradation of grip force, and no grip electrode interference with the plasma.

Electrogrip www.electrogrip.com mail@electrogrip.com 6945 Lynn Way Pittsburgh PA 15208 USA ph: (1) 412-247-0992; (1) 412-247-0993