Non-Contacting Eddy Current Conductivity Sensor

for Measuring Doped Silicon Wafers

For MEMS Applications

A Finite Element Analysis (FEA) using flexPDE

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Purpose of the Numerical Experiment:

The purpose of this numerical experiment is to learn something about the electromagnetic fields, induced currents and absorbed power in and around a silicon wafer placed above a "cup core" coil excited at an RF frequency.

For this analysis, I used an excitation frequency of 5 MHz. However, because I wanted the option of exciting the system at substantially higher frequencies, I employed the full blown Helmholtz wave equation formulation for media that are specified by their permeability, permittivity and conductivity. Because the excitation is sinusoidal, the various field parameters are complex valued.

Using the wave equation approach, the excitation frequency in the model could be raised high enough for radiation of energy from the system to occur … and … be accurately evaluated. I was interested in this from a "how much EMI shielding do I need" and "will the shielding lower the performance of the sensor" point of view.

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The Model Geometry

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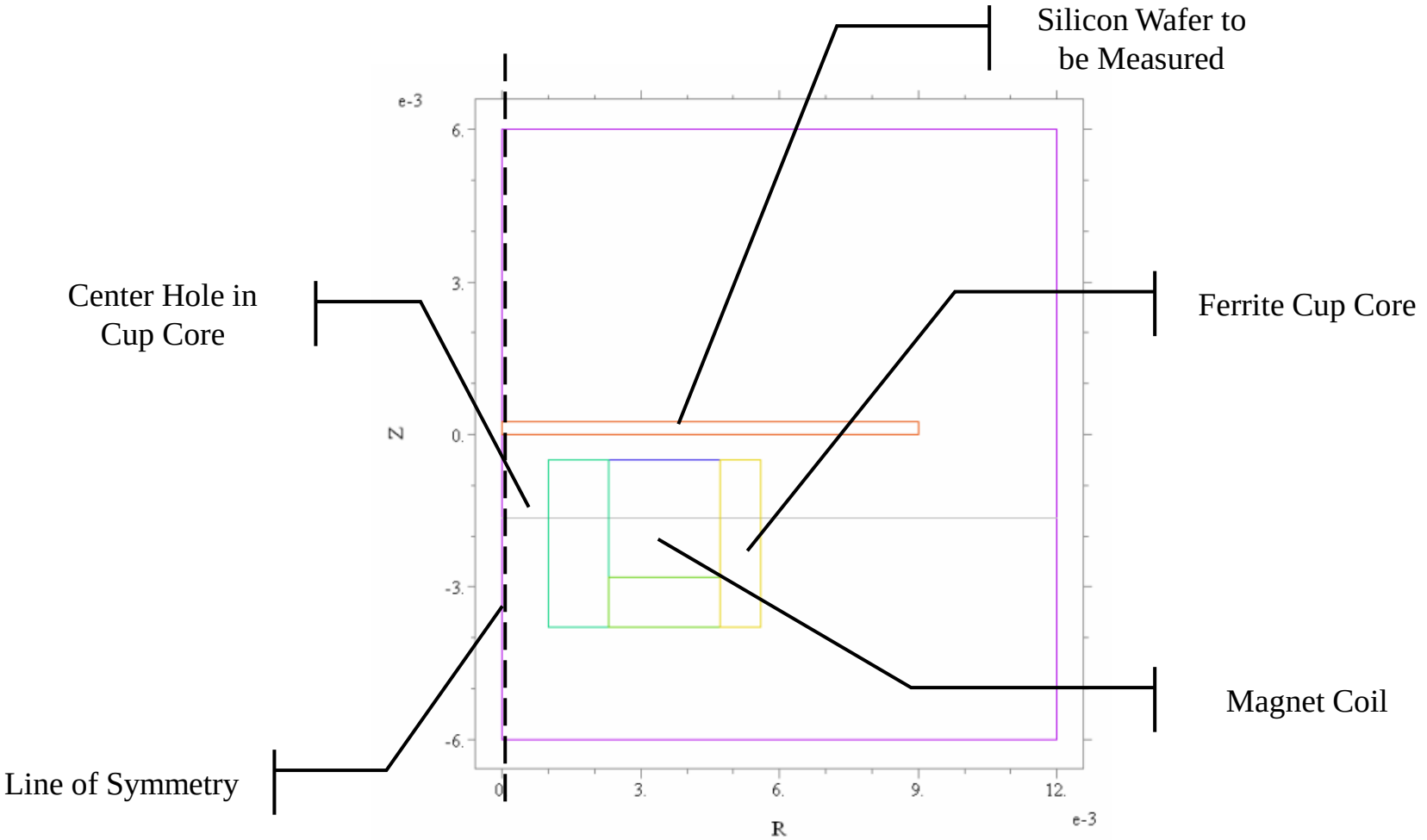

Solution Domain

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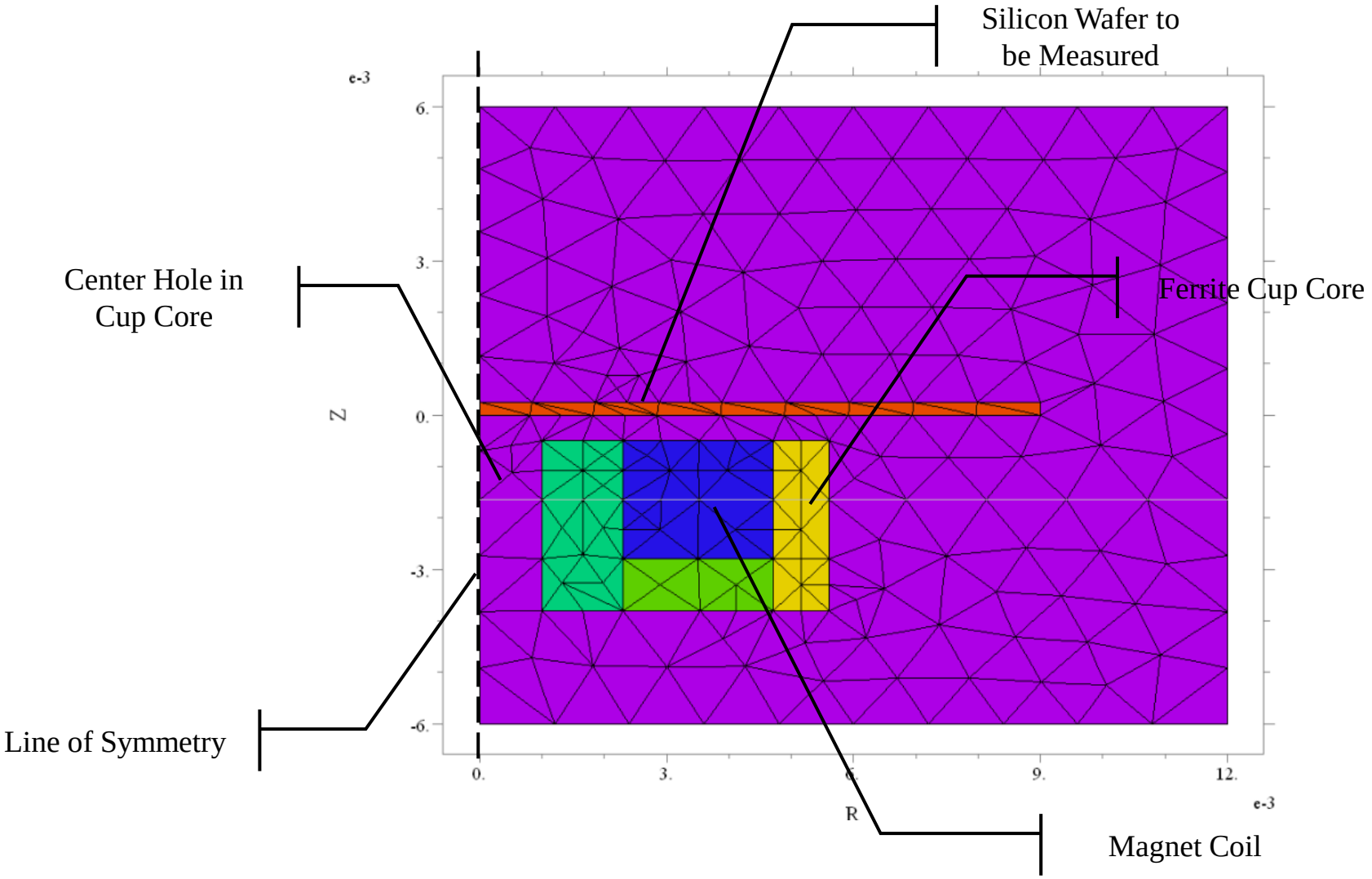

Analysis Grid

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Various Field Plots

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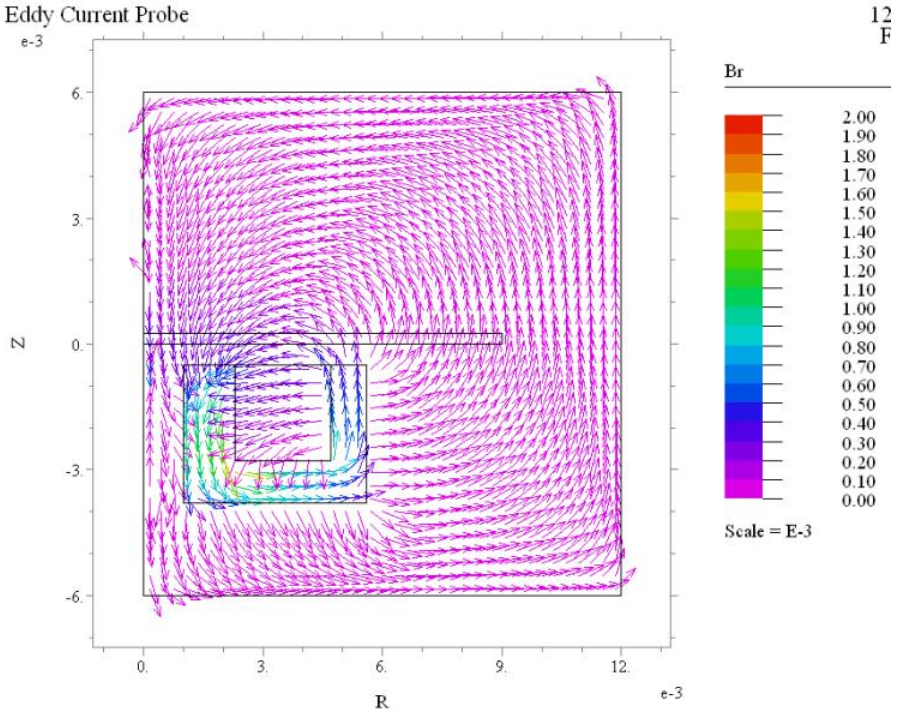

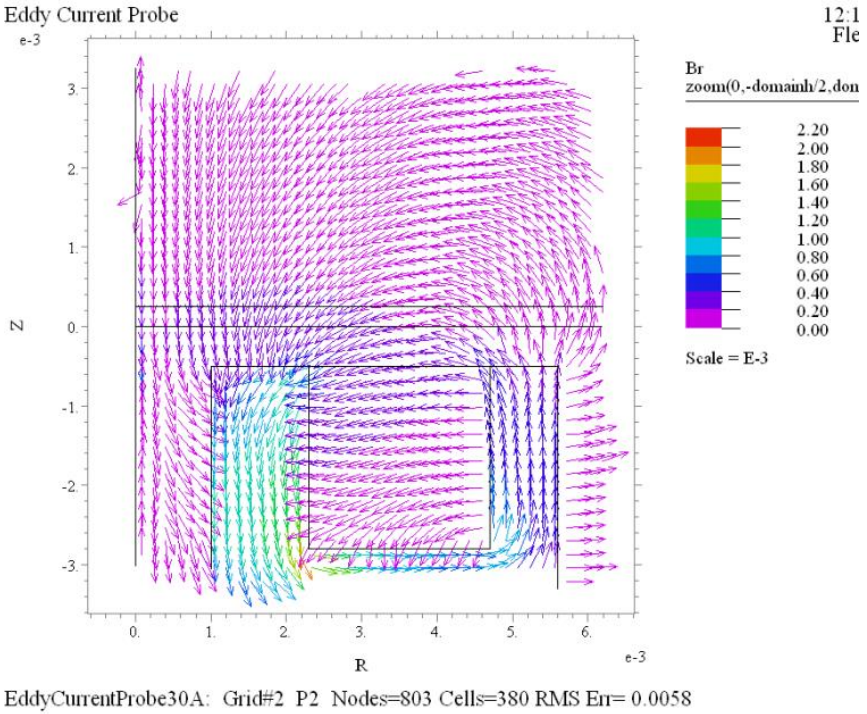

B field – Real Component

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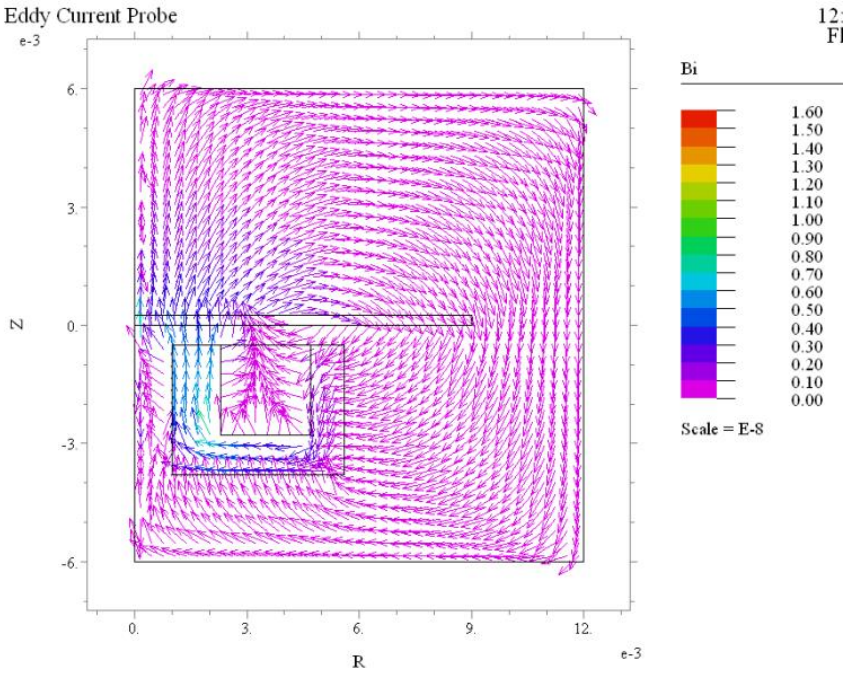
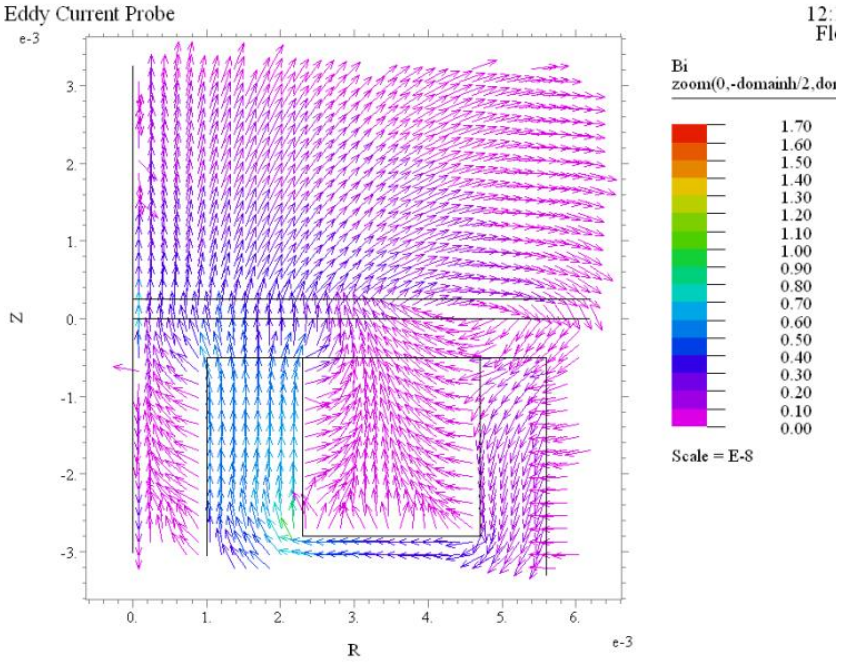


EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058



EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058

B field – Imaginary Component

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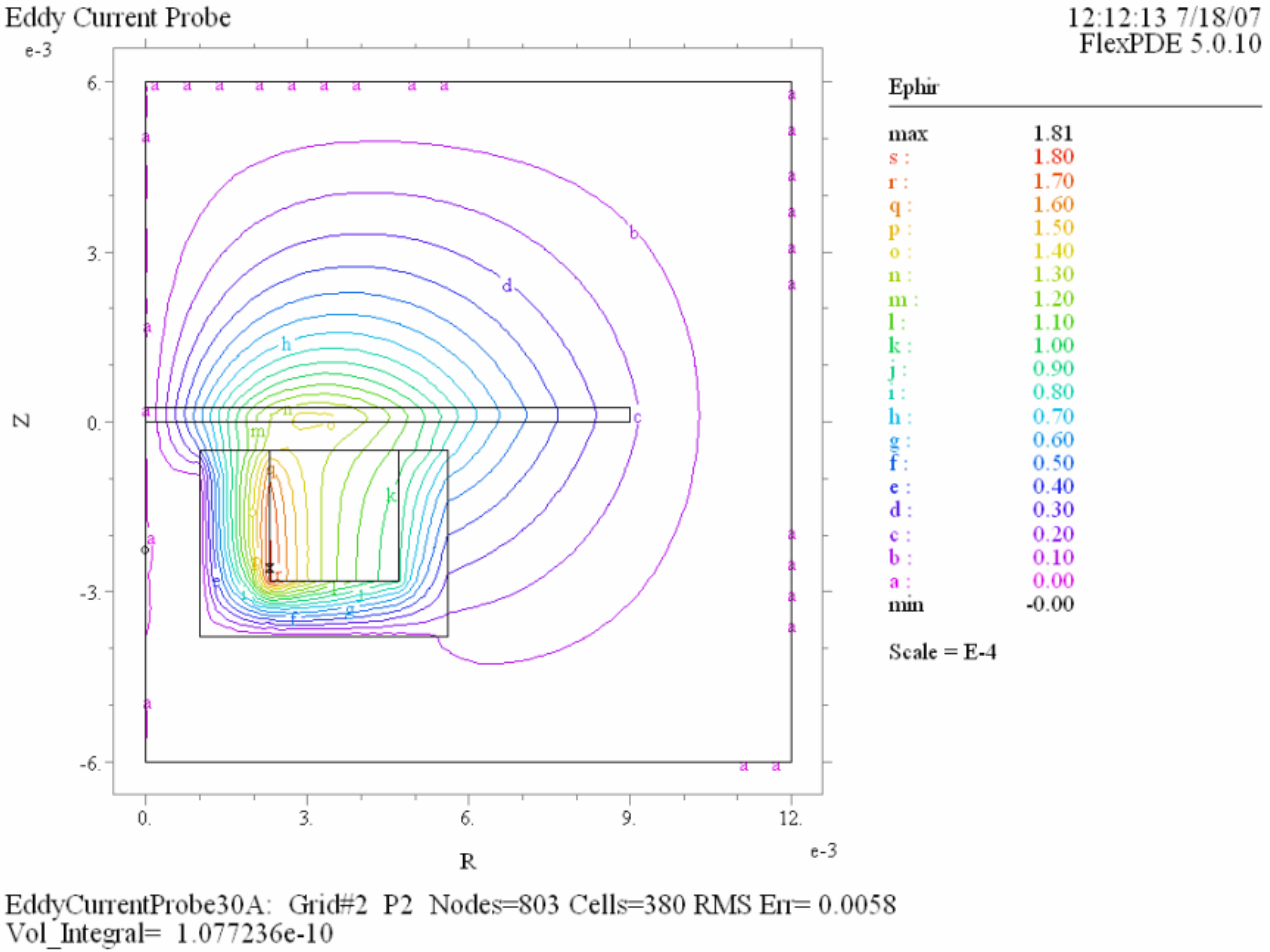

E field – Azimuthal - Real Component

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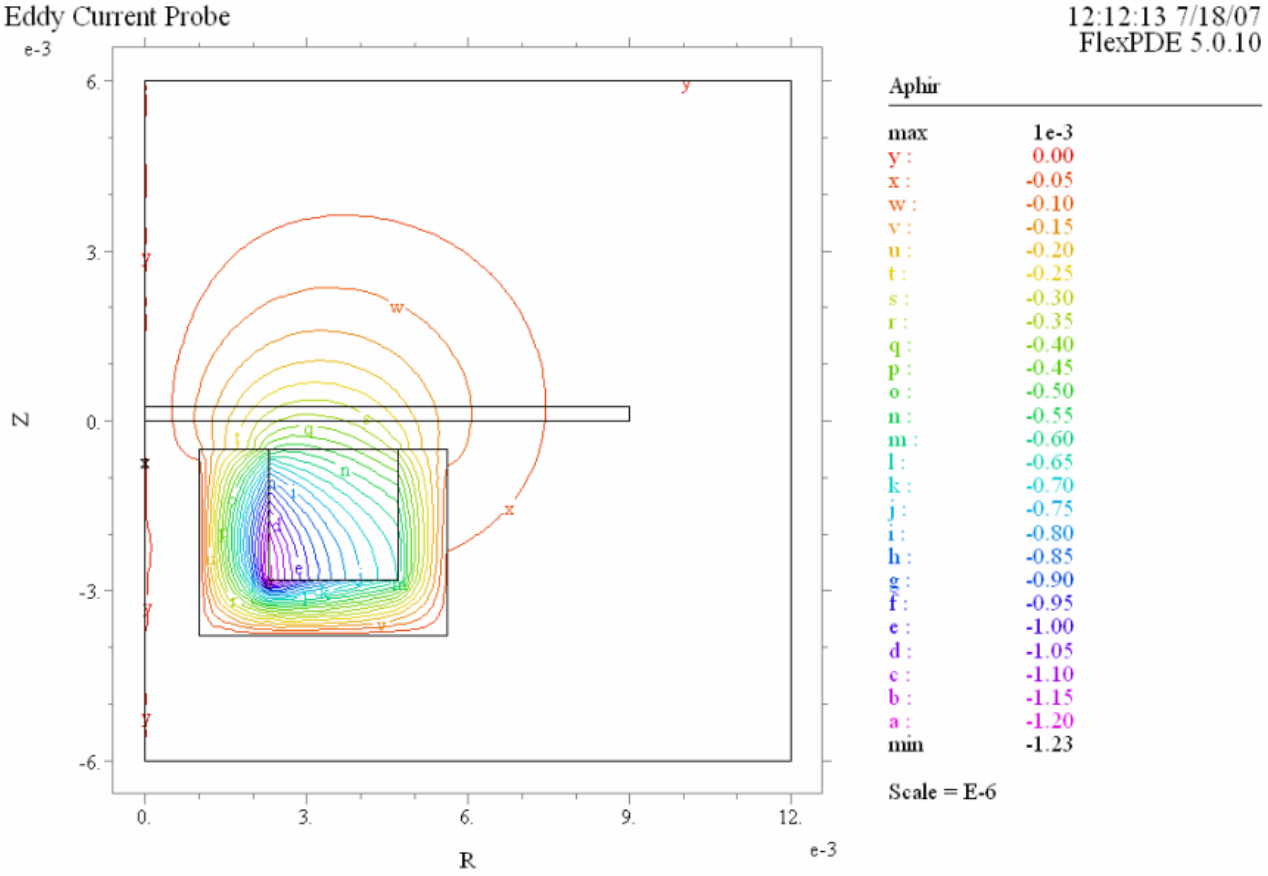

EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Er= 0.0058
Vol_Integral= -2.861614e-13

Vector Magnetic Potential field – Azimuthal - Real Component

{This field effectively shows the magnetic lines of flux}

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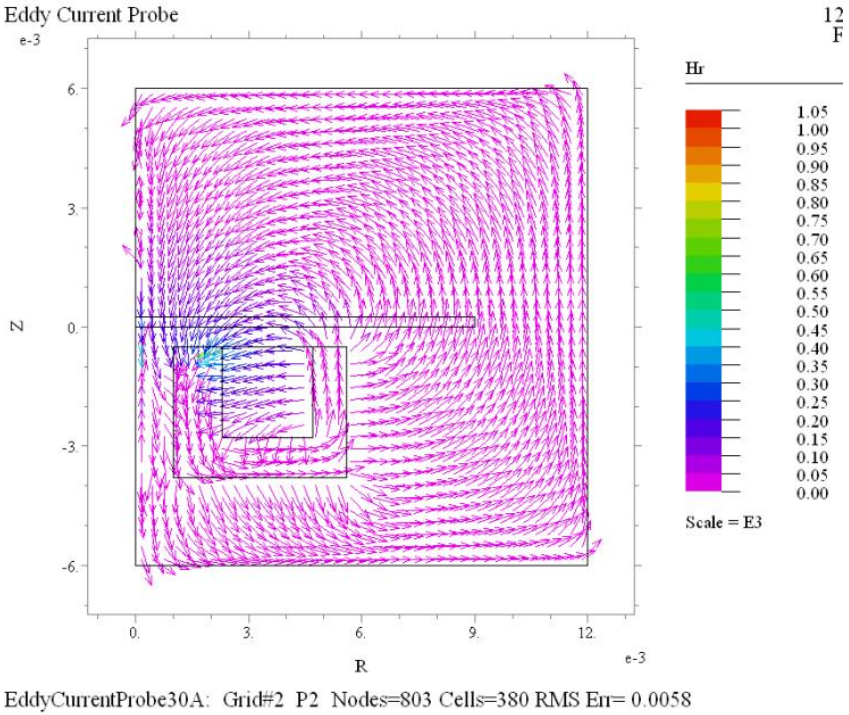
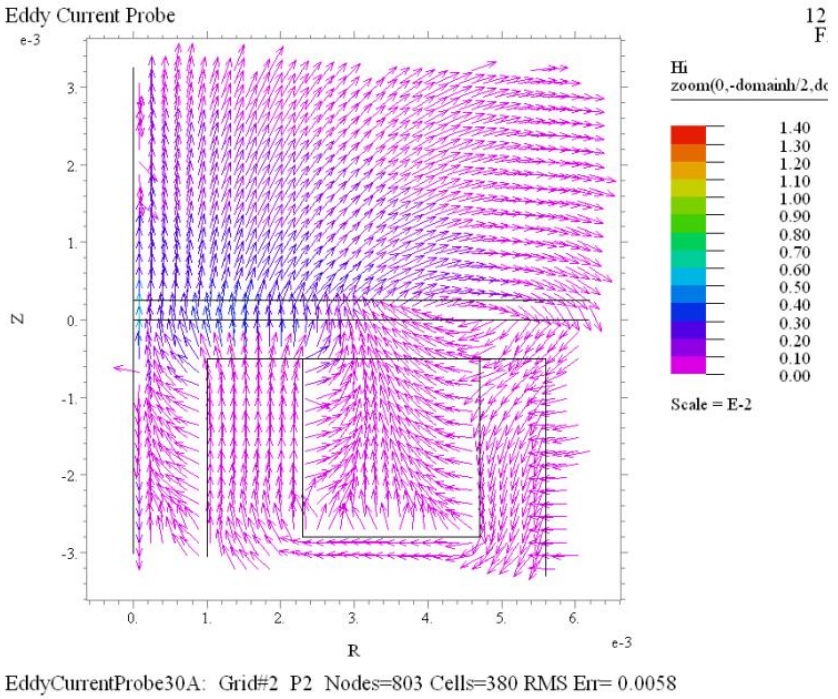


EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058



EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058

H Field - Real Component

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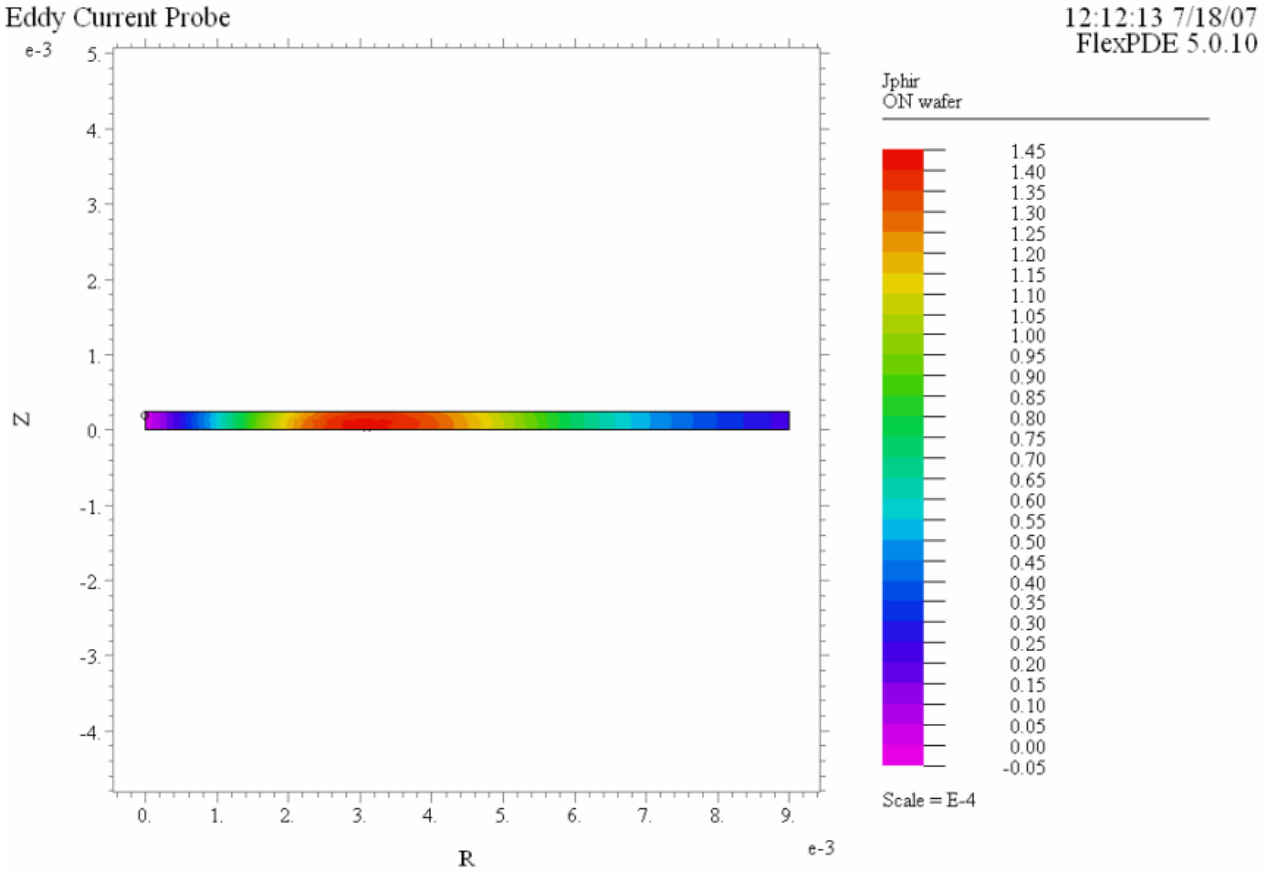

EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058
Vol_Integral= 4.619920e-12

Induced Current Density – Azimuthal - Real Component

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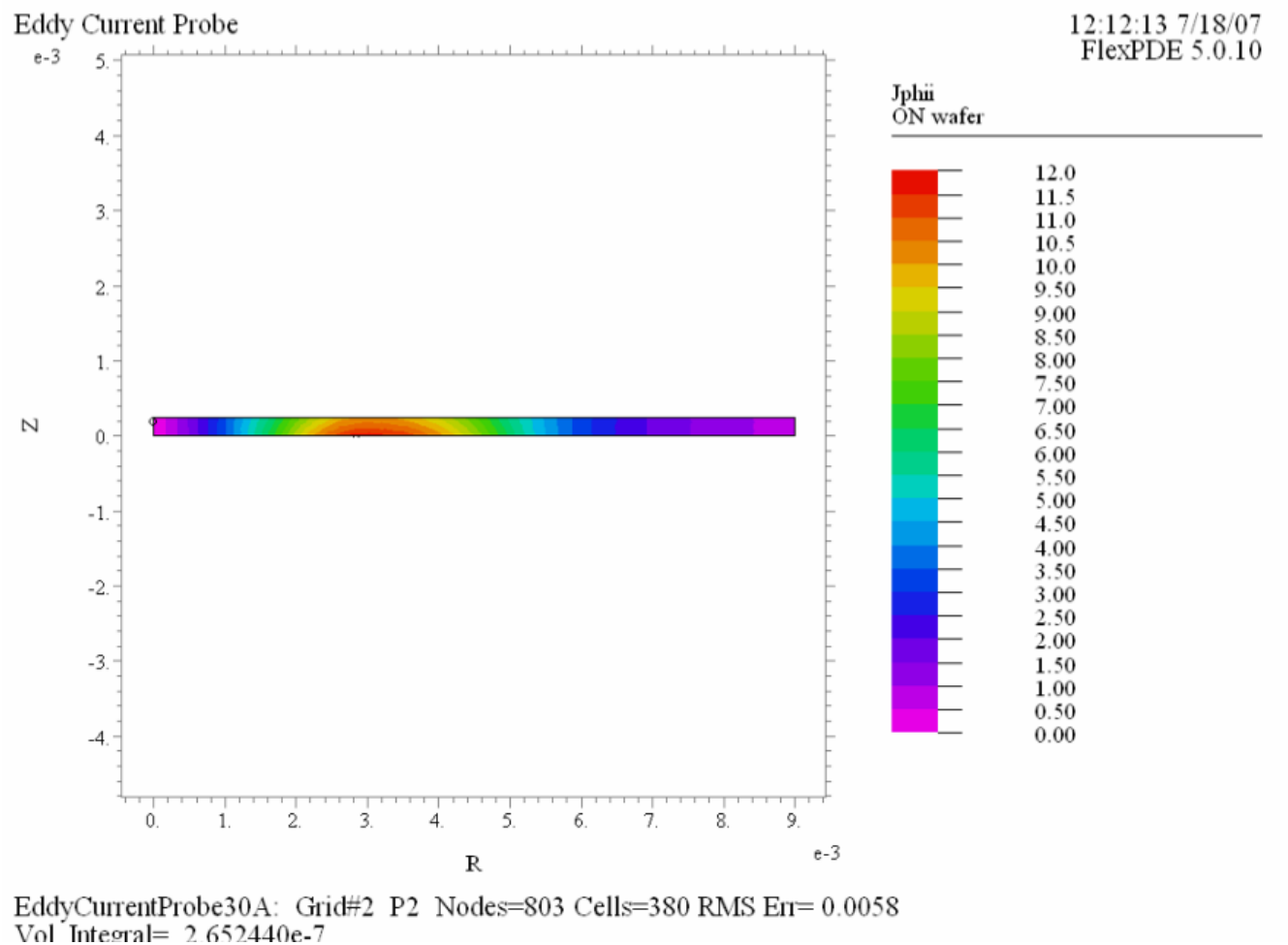

Induced Current Density – Azimuthal - Imaginary Component

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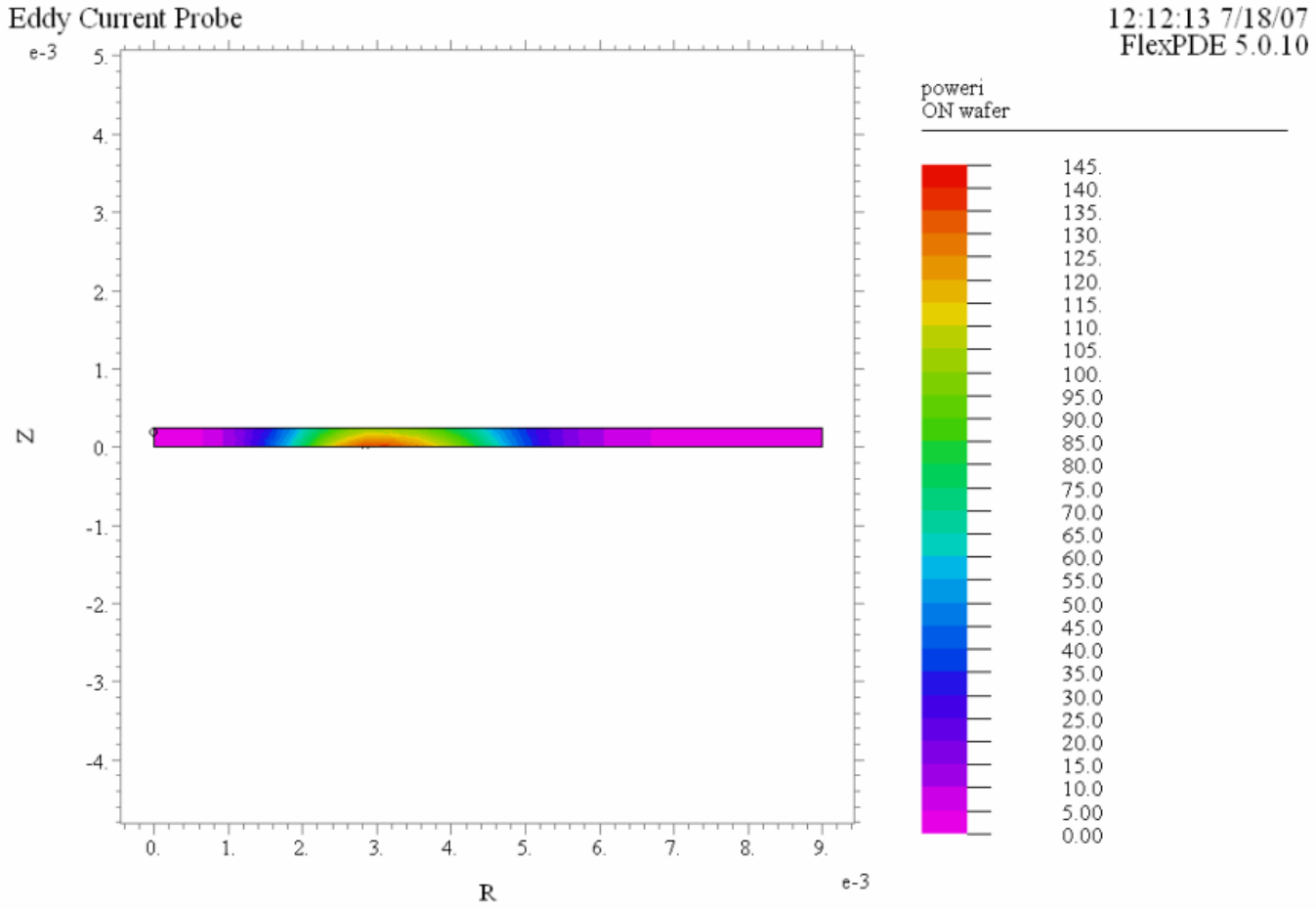

EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058
Vol Integral= 1.855982e-6

Ohmic Power Loss Density

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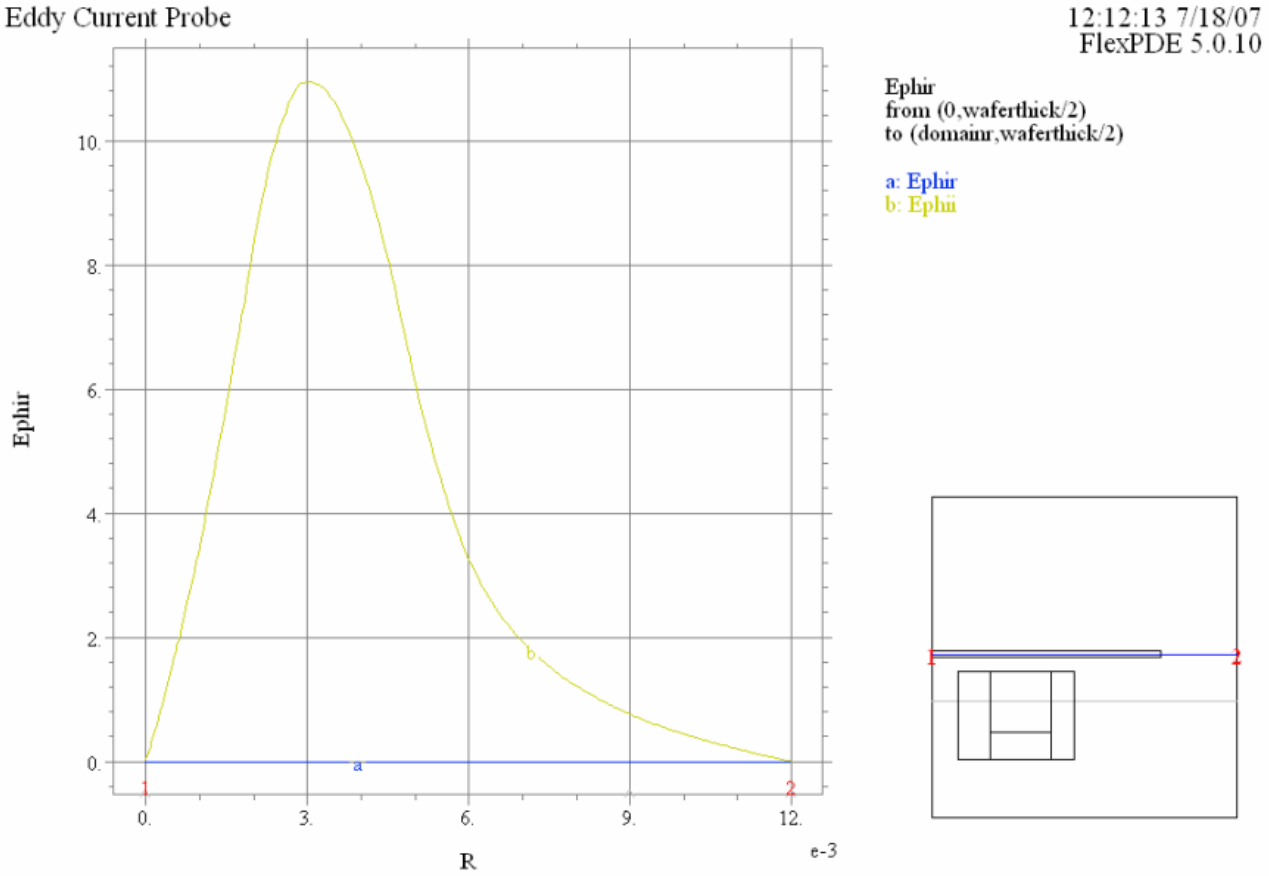

E Field on Wafer Center Plane – Azimuthal - Real Component

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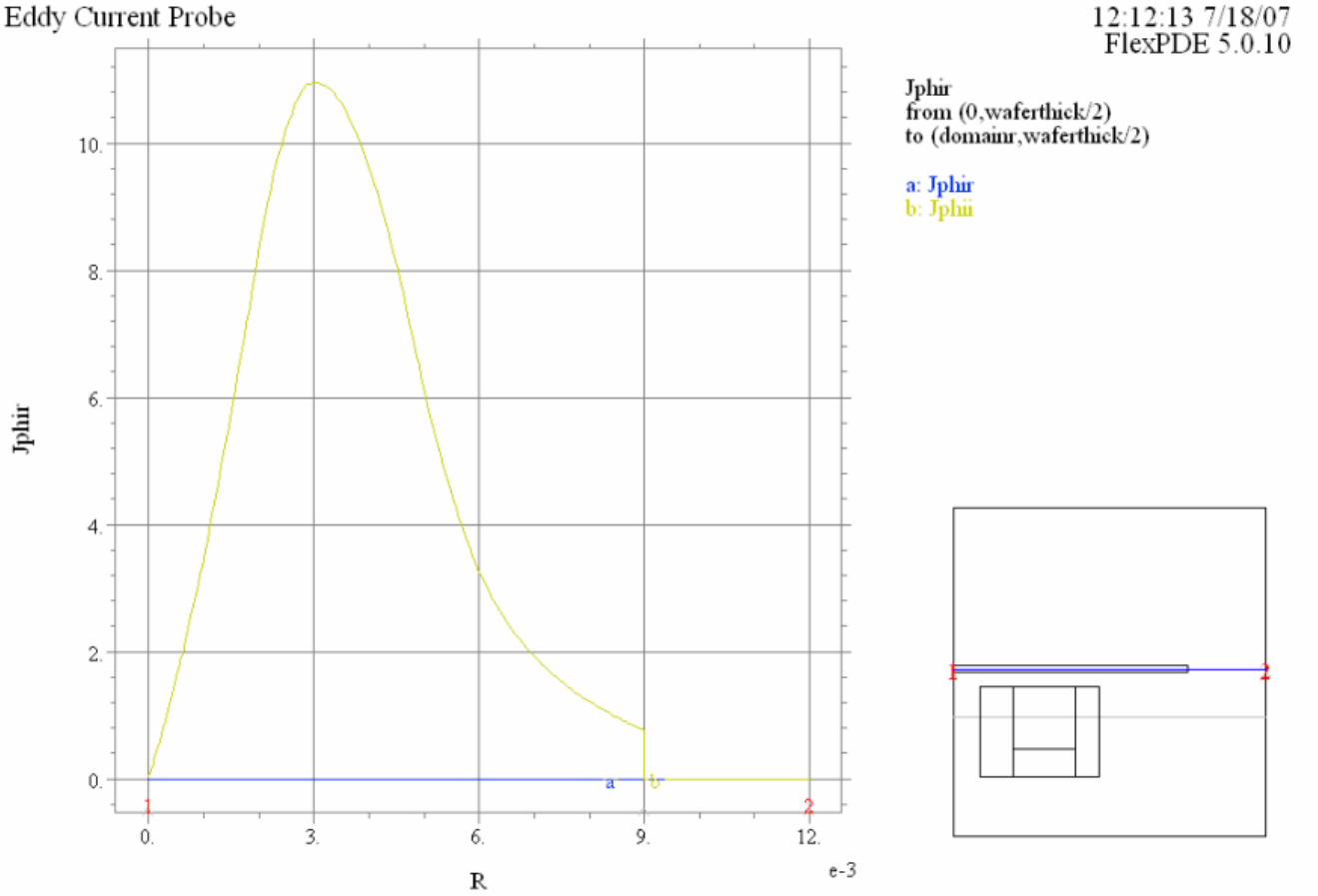

EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058
Surf_Integral(a)= 1.862078e-8 Surf_Integral(b)= 1.060238e-3

Current Density on Wafer Center Plane – Azimuthal - Real Component

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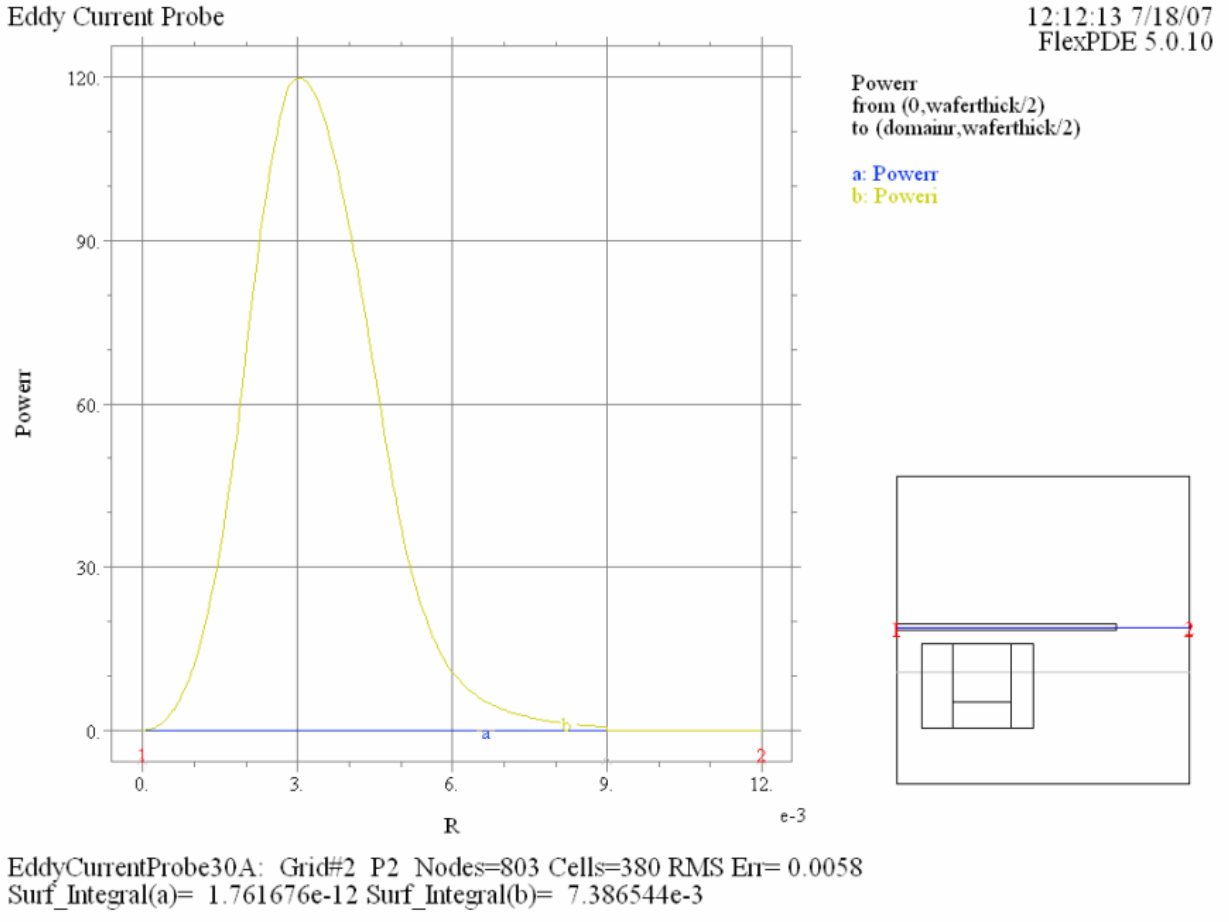

Ohmic Power Dissipation on Wafer Center Plane

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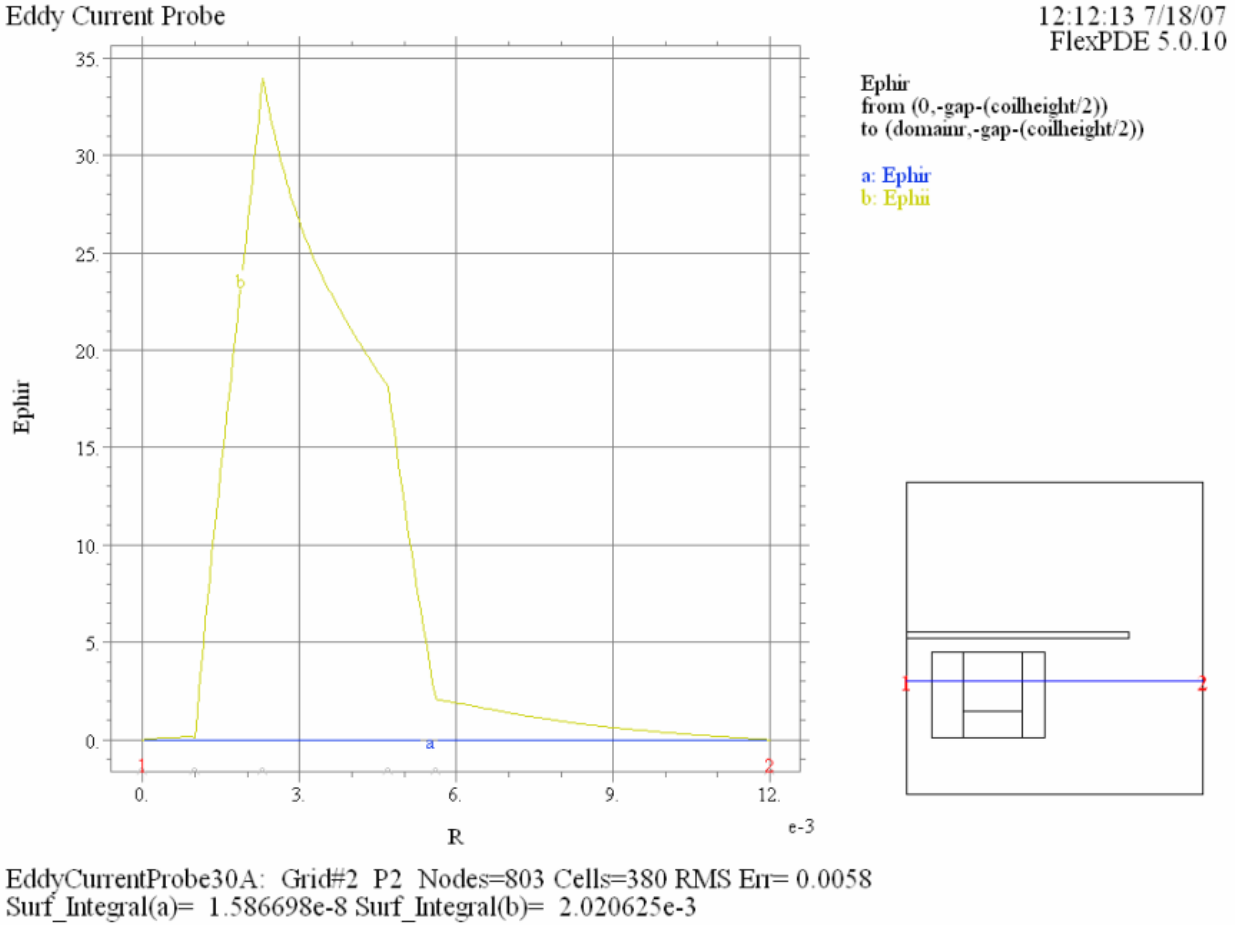

E Field on a Cut Plane – Azimuthal - Real Component

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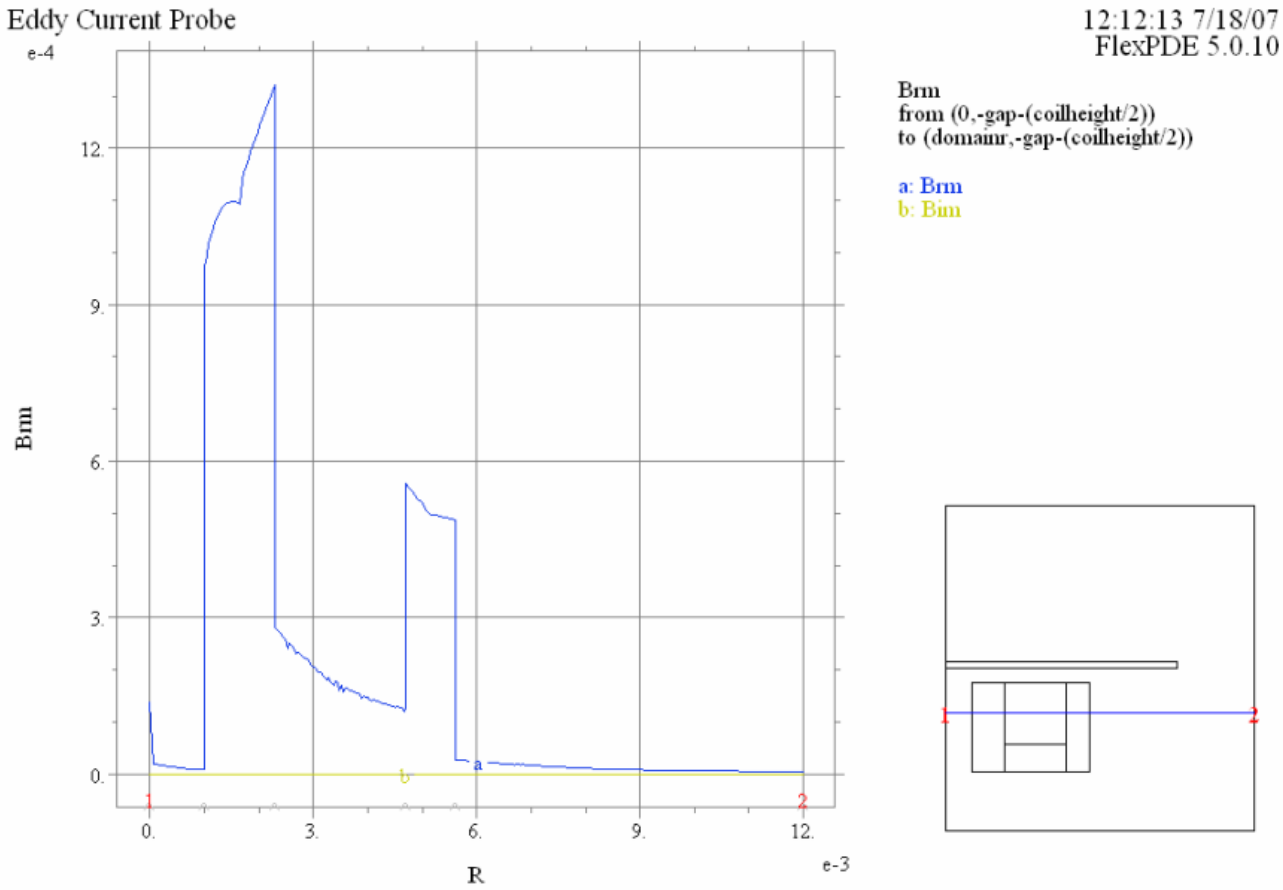

EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Er= 0.0058
Surf_Integral(a)= 4.318249e-8 Surf_Integral(b)= 2.168614e-13

B Field on a Cut Plane – Azimuthal - Real Component

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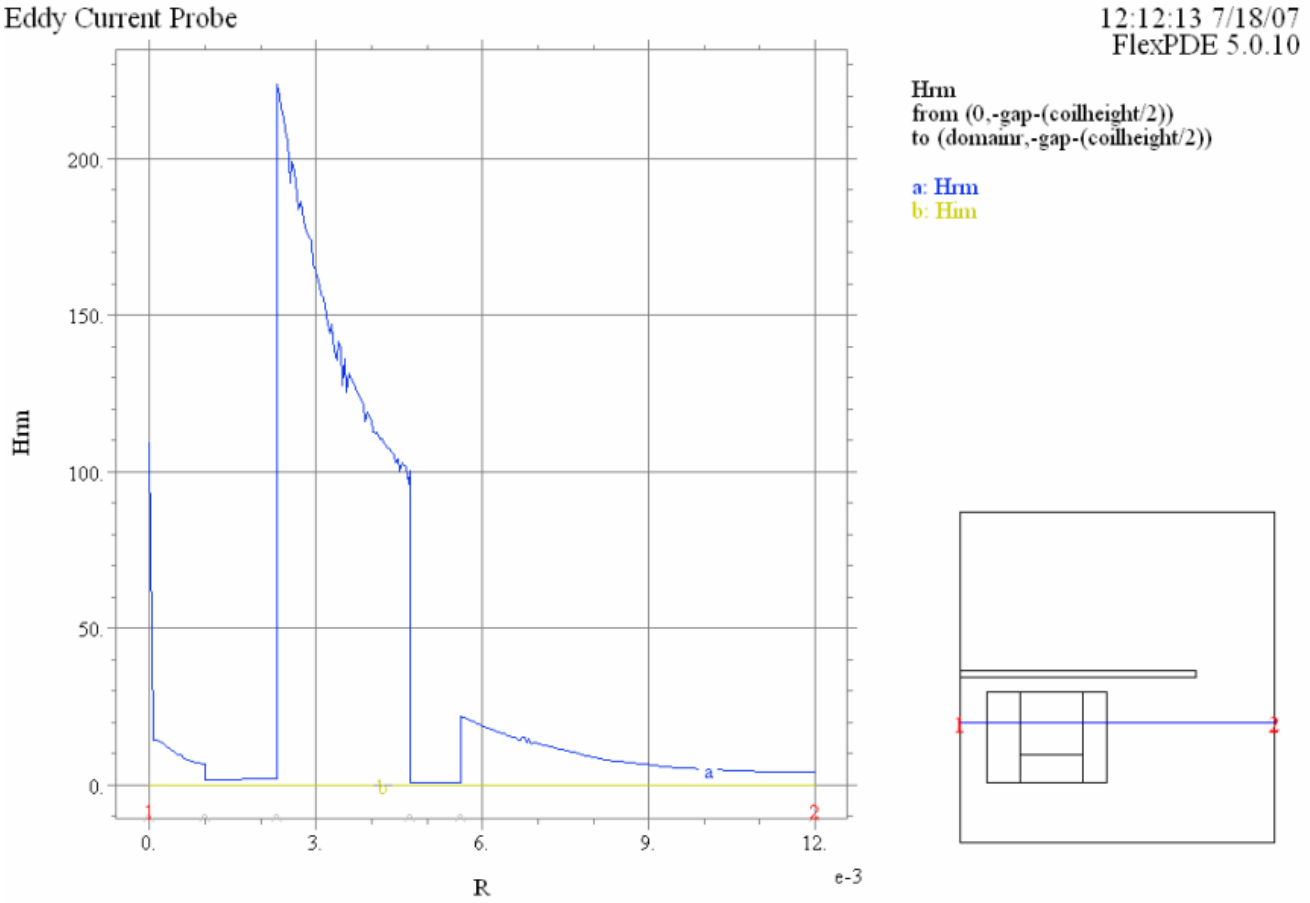

EddyCurrentProbe30A: Grid#2 P2 Nodes=803 Cells=380 RMS Err= 0.0058
Surf_Integral(a)= 0.010082 Surf_Integral(b)= 7.649214e-8

H Field on a Cut Plane – Azimuthal - Real Component

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Summary of Model Parameters and Resultant Values

Coil Geometery:

coilwidth= 2.400000e-3
coilheight= 2.300000e-3
coilir= 2.300000e-3
coilor= 4.700000e-3
coilwindarea= 8.050000e-6

Material Parameters:

mu0= 1.256637e-6
muferrite= 500.0000
eps0= 8.850000e-12
epsSilicon= 11.70000
sigmacopper= 0.000000
sigmawafer= 1.000000

Coil Current Parameters:

freq= 5000000.
omega= 3.141593e+7
currentcoil= -0.050000
N= 20.00000
Jphicoil= -124223.6

Impedance Parameters:

waferthick= 2.500000e-4
sigmacopper= 0.000000
sigmawafer= 1.000000
Zreal= 4.783306e-15
Zimag= 1.776399e-5
Rcoil= 1.092728e+12
Zcoilr= 1.092728e+12
Zcoili= 2.968406
Zintegralr= -1.914173e-15
Zintegrali= 1.051802e-20
Lpoweri= 5.654454e-13
Lpowerr= 1.522573e-22
Zar= 1.641905e-5
Zai= 2.988100
La= 9.511419e-8
L11= 9.448730e-8
Lcalc1= 3.647194e-6
Lcalc2= 3.494513e-6

Power Parameters:

sigmacopper= 0.000000
sigmawafer= 1.000000
Bflux1r*omega= 2.091582e-4
emf1r= 8.144751e-7
emf1i= 0.148420
emftotr= 1.628950e-5
emftotI= 2.968406
IRdrop= -5.463639e+10
powercoilr= 0.000000
powercoili= 0.000000
powerwaferr= 1.195826e-17
powerwaferi= 4.440998e-8
powertotalr= 1.195826e-17
powertotali= 4.440998e-8

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Summary and Conclusions

A finite element model has been developed that allows insight into the nature and magnitude of electromagnetic fields, induced currents and absorbed power in a silicon wafer placed above a “cup core” coil excited at an arbitrary RF frequency.

The model uses the Helmholtz “full wave” formulation which allows analysis of radiation from the system. This model could be developed in many further ways.

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