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Initiation of Quasi Spherical Direct Drive Capsules for Inertial Fusion

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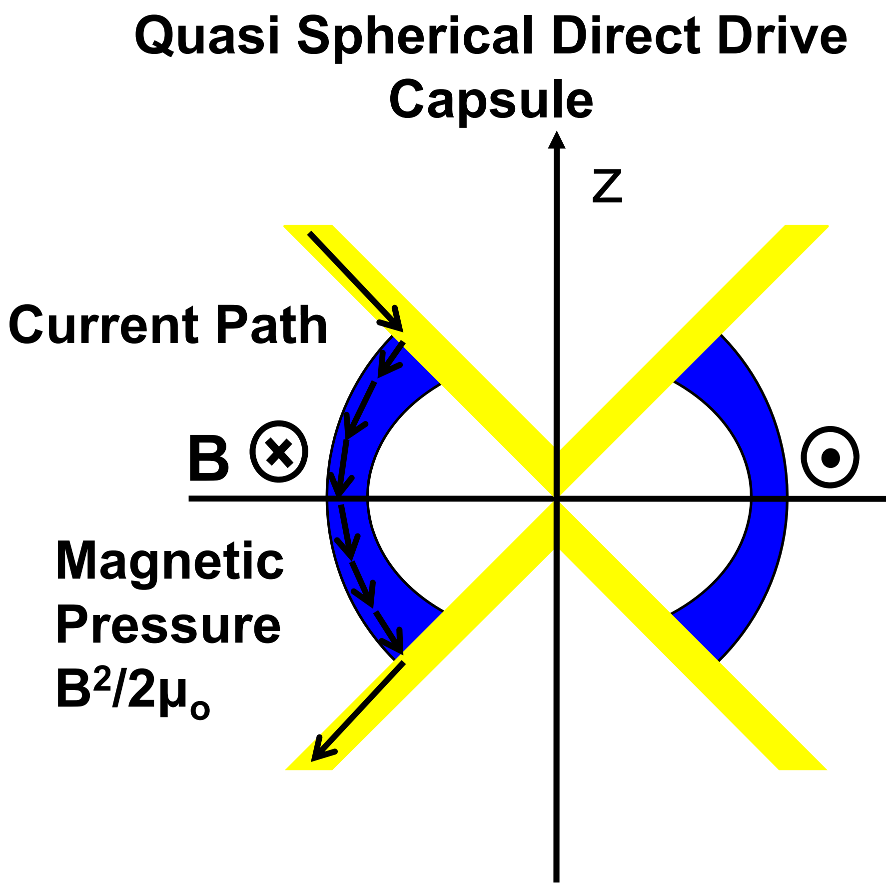
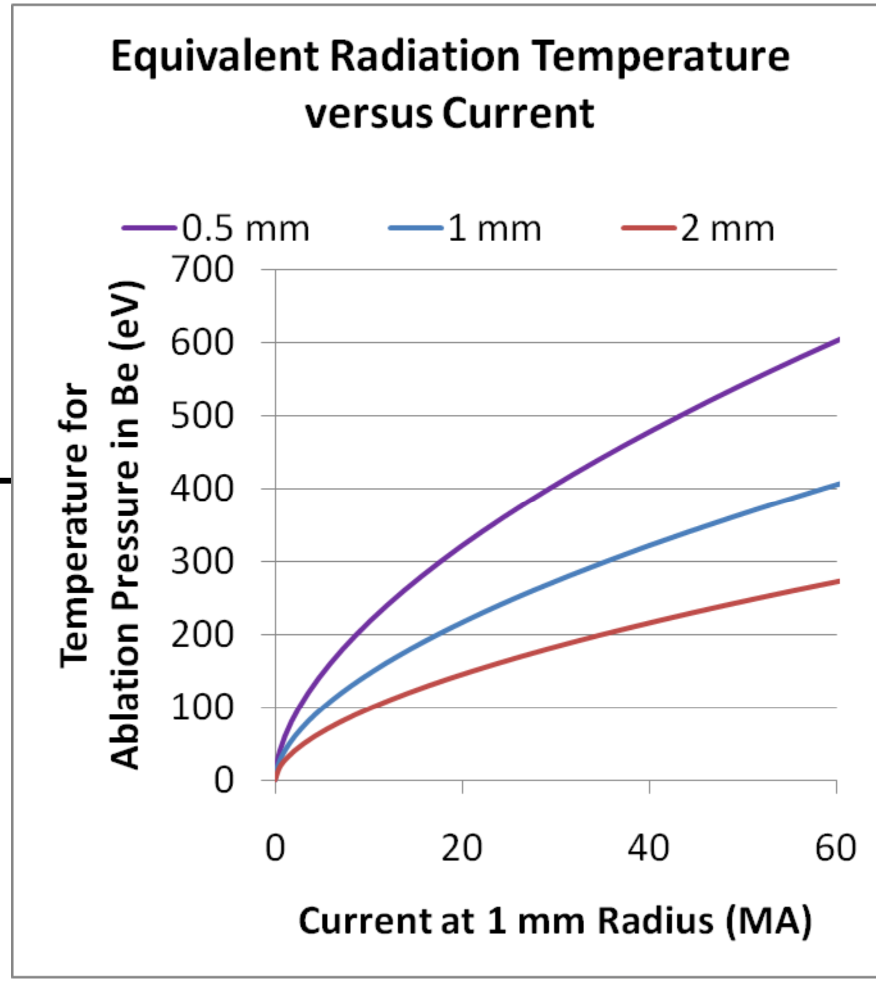
Magnetic pressure can substitute for ablation pressure in a hohlraum.





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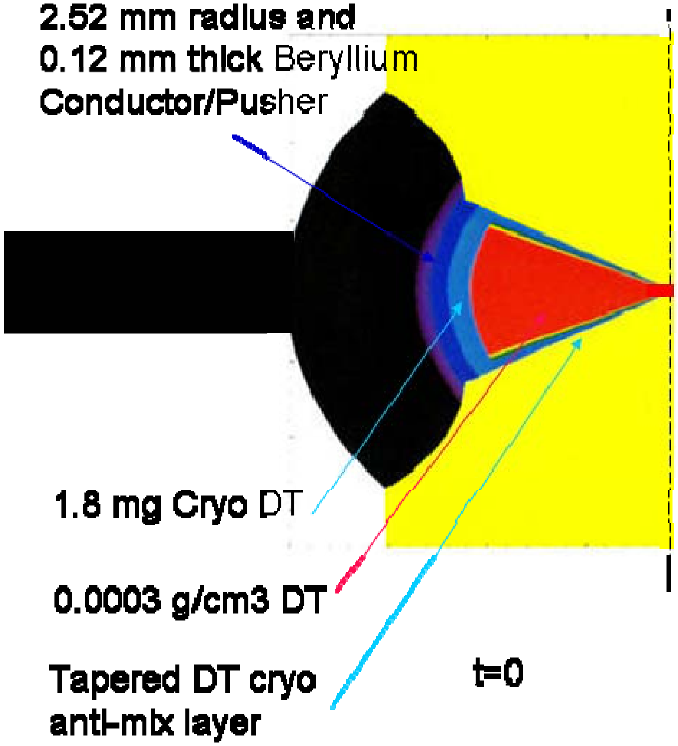
Quasi Spherical Direct Drive capsule offers 500 MJ 1D yields with 85 MJ energy store.



Many issues are mitigated with a higher dI/dt.

- Uniform Initiation
- Internal Pulse Shaping
- Less growth of Magnetic Rayleigh Taylor instability
- Lower driver energy
- Higher ηG
- Lower Cost of Electricity

2D simulated yield is currently limited by a wall instability. Three possible solutions are being examined with LASNEX.

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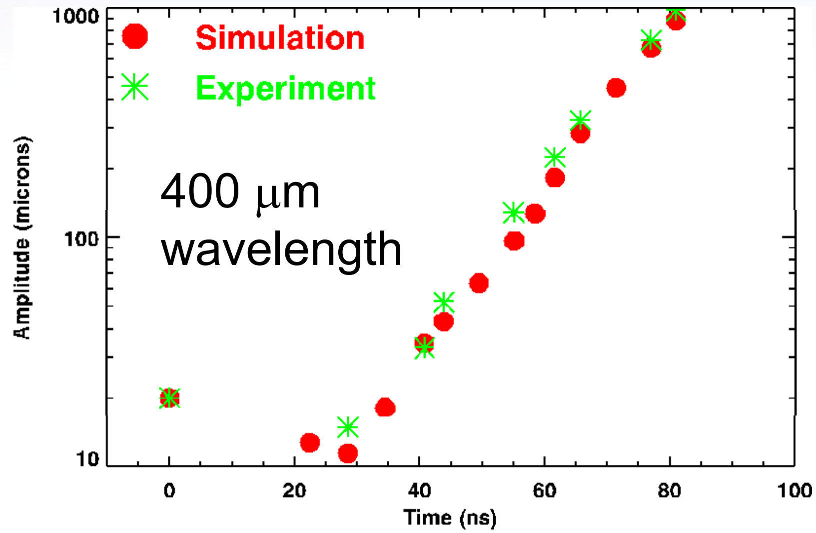
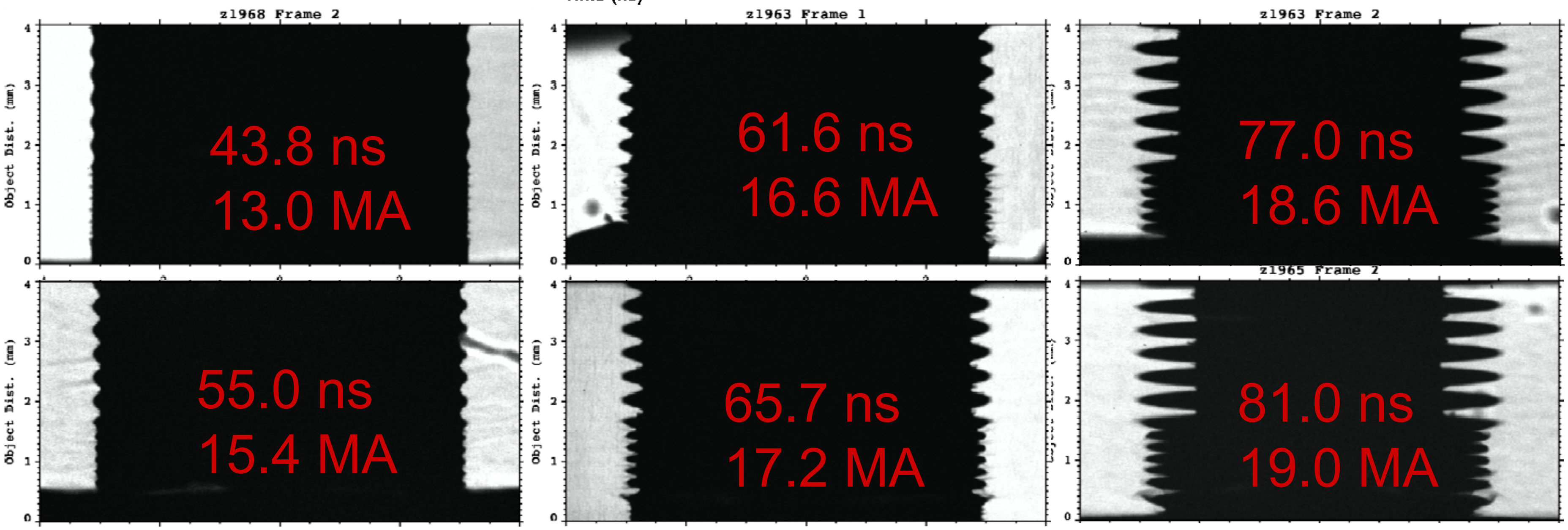
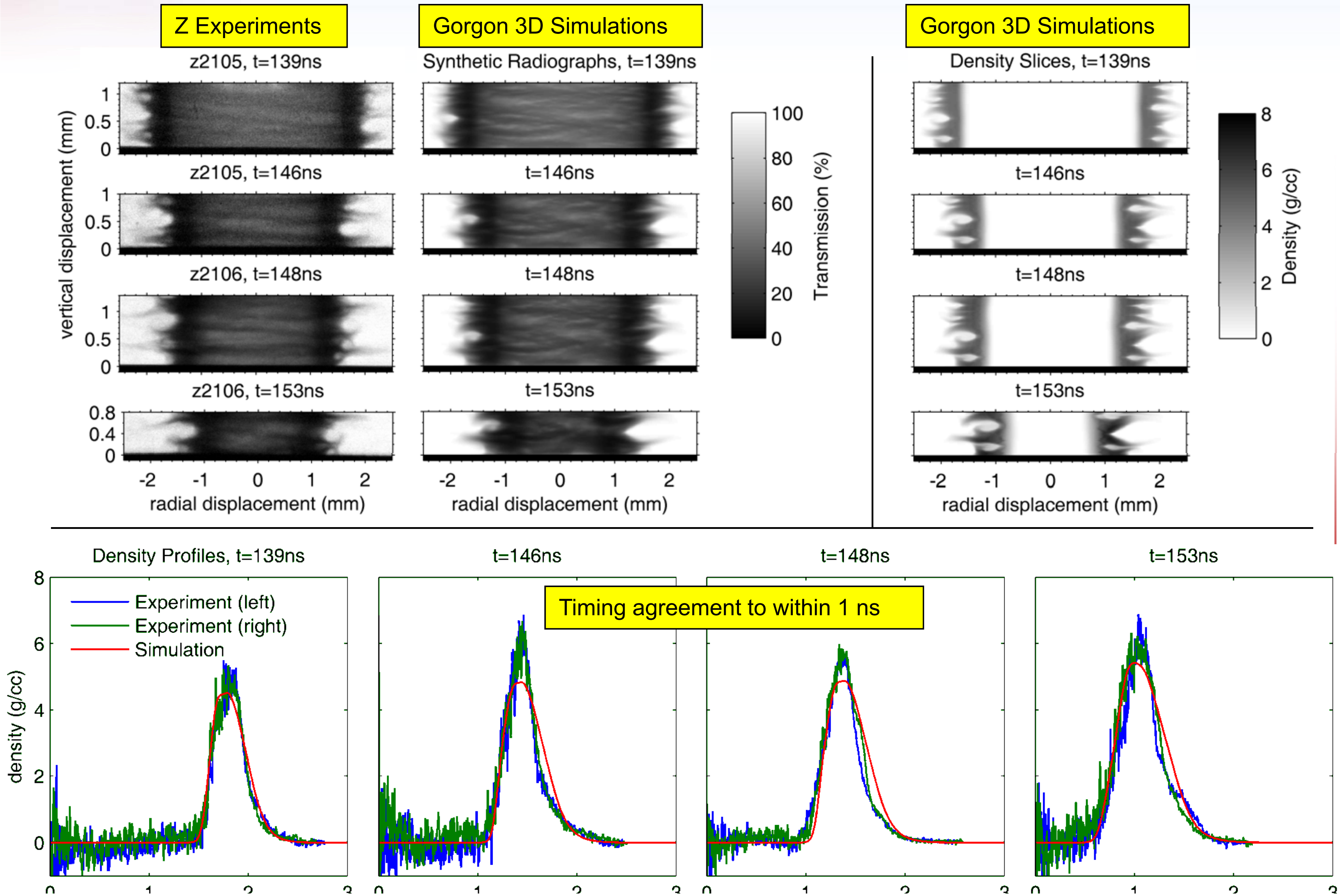
Experiments have validated LASNEX simulations of cylindrical Magnetic Rayleigh Taylor (MRT) Instability.



- D. Sinars et al. PRL **105**, 185001 (2010) and Physics of Plasmas **18**, 056301 (2011)
- Longer wavelengths compared well.
- Shorter wavelength growth was less than 2D predictions.

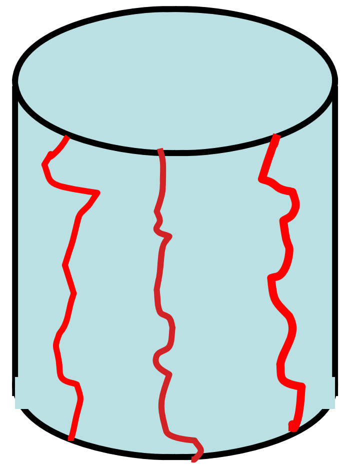


Gorgon 3D simulations capture features of multi-mode MRT growth



Could the excellent agreement be improved and extended to higher convergence with better initiation?

- SCORPIO Experiment
- Vapor deposited aluminum on parylene on diamond turned wax.
- R= 1 cm and H=2 cm
- 0.02 to 0.2 microns of Aluminum
- 0.0075 microns of Al_2O_3
- Few monolayers of adsorbed gas



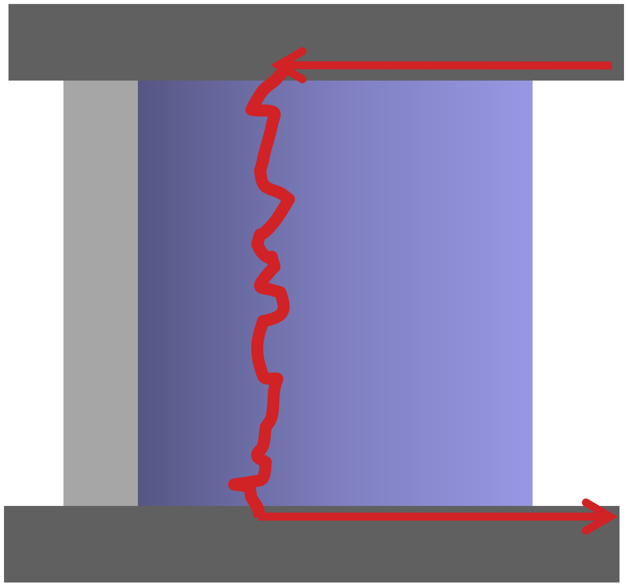
Diagnosed with
•Schlieren photography,
•Holography,
•Open shutter photography, and
•Multiple double Langmuir probes

The uniformity of the plasma depends on the rate of rise of current density.

- $dJ/dt = 8 \times 10^{16}$ A/cm²/s
  - Uniform discharge in 7 ns
  - 0.1 microns Al at $dI/dt = 5 \times 10^{12}$ A/s
- $dJ/dt < 4 \times 10^{16}$ A/cm²-s
  - Very non-uniform breakdown
  - Azimuthally asymmetric current
- 0.03 to 0.05 microns Al showed bumps on the plasma surface as seen with the Schlieren photography
  - Thin film effects
  - Defects in thinner coatings.

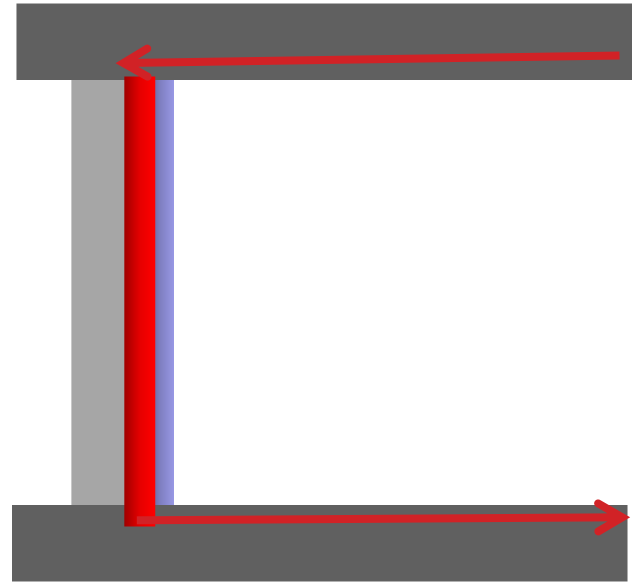
Data suggest two modes of initiation.

Slow Mode



- Adsorbed gas expands before voltage increases
- Gas breakdown shunts metal

Fast Mode



- Metal becomes plasma before adsorbed gas expands
- Metal initiates uniformly

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1D LASNEX simulations with three monolayers of hydrogen on metal indicates Z initiation is slow mode.

dJ/dt = 8 x 10^{16} A/cm^2/s gave uniform discharge in 7 ns.

Z experiments may have too low a dJ/dt at burst

- 100 ns Z pulse with prepulse and thick Al or Be conductor: dJ/dt ~1x 10^{15} A/cm^2-s in 86 ns
- 100 ns Z pulse with no prepulse and thick Al or Be conductor: dJ/dt ~5x 10^{15} A/cm^2-s in 45 ns
- 100 ns Z pulse with no prepulse and 25 micron thick conductor: dJ/dt ~2x 10^{16} A/cm^2-s in 20 ns
- 100 ns Z pulse with no prepulse and 6.25 micron thick conductor: dJ/dt ~8x 10^{16} A/cm^2-s in 8 ns
- Possible 44 ns Z pulse with no prepulse and thick Al or Be conductor: dJ/dt ~5x 10^{16} A/cm^2-s in 7.5 ns

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Initiation and dielectric breakdown should be the same statistical process.

- $V(t)$ = Voltage , ℓ = channel length, N = number of channels
- $\sigma(V)/V$ ~ 0.3% for fast discharges in solids, liquids, and gases
- $\Delta T = \dfrac{2\,[\sigma(V)/V\,]V}{[dV/dt]}$

  = 2 sigma timing of channel formation

  = Transit time isolation + inductive time + resistive time for channel heating

  $= 0.8\,\pi\, r_o /Nc + \mu_o\, \ell\, \ln(r_o / r_i)/NZ$

  $+ 0.088\, (\rho/\rho_o)^{1/2} /(NZ(V/\ell)^4)^{1/3}$

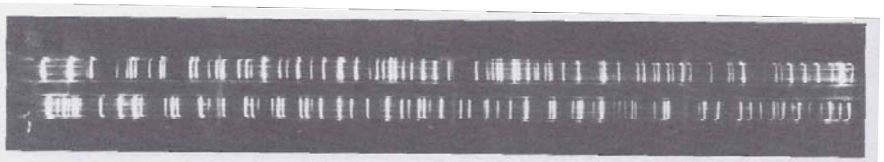


Fig. 10c-10 Multichannel breakdown corresponding to ~ 140 channel entry in Table 10c-XII.

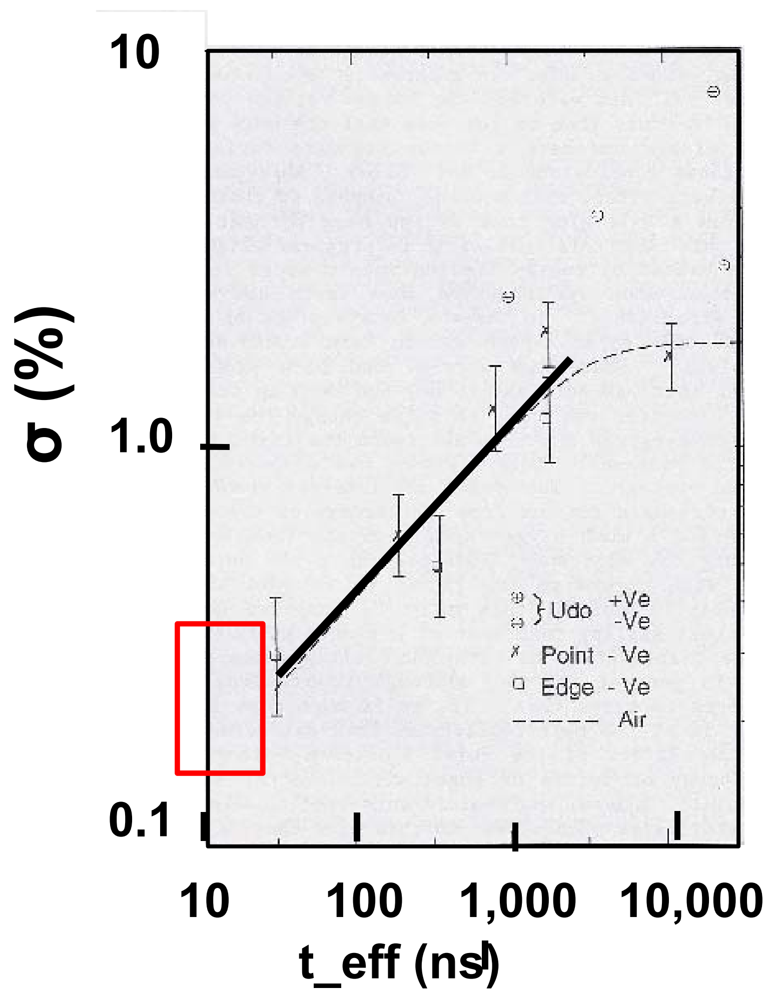
J. C. Martin, "Multichannel Gaps" J. C. Martin on Pulsed Power, Vol 3, pp 295-333 edited by T. H. Martin, A. H. Guenther and M. Kristiansen , Plenum Press, New York, (1996)

Compute V, dV/dt, ρ with LASNEX and solve for N.

Calculation has one empirical parameter.

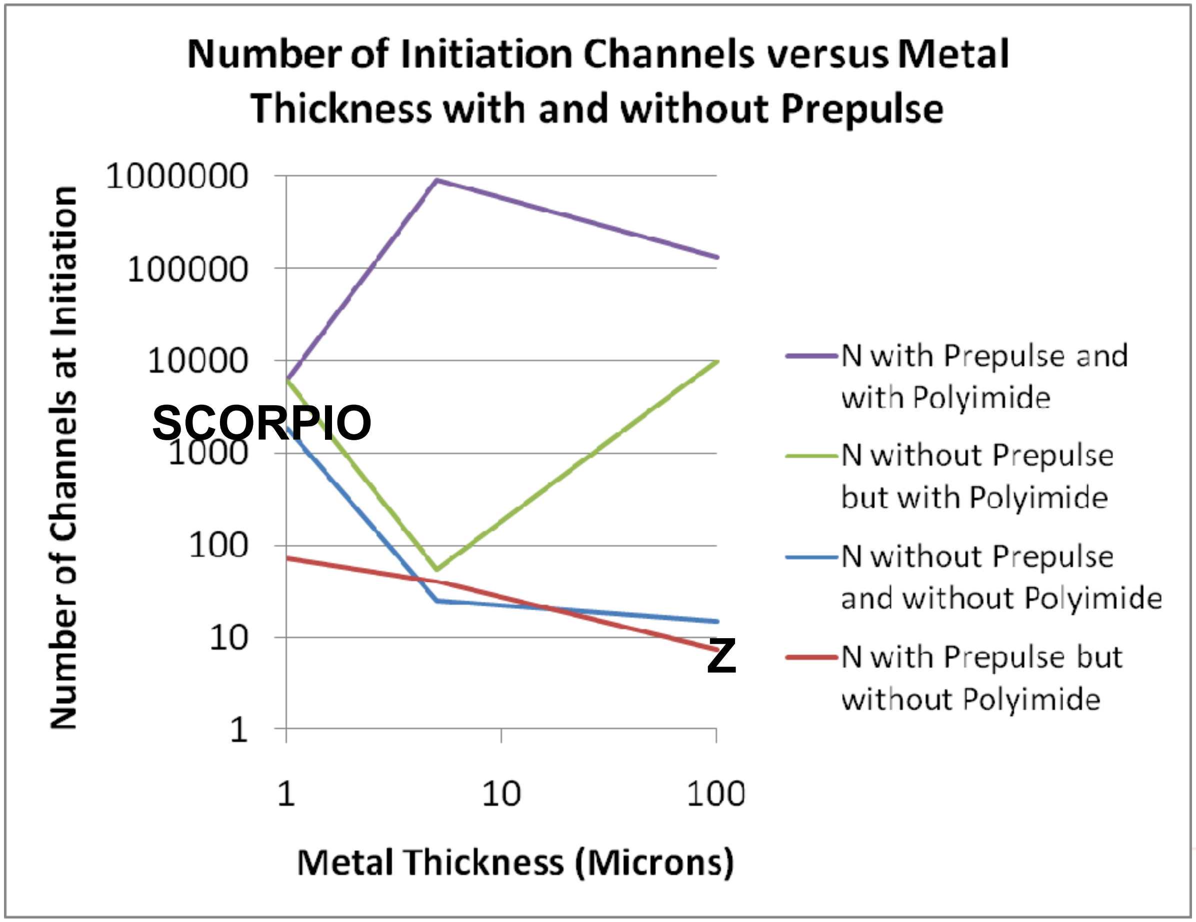
- Radius = 0.0025 m for QSDD
- $Z = L_{vac}/\tau_{vac}$ = 13 nH/5 ns = 2.6 Ohmss
- l = 0.0025 m
- σ(V)/V =0.18 to 0.3% from J.C. Martin

- Vary metal thickness
- 0 or 2 micron coating of Polyimide from Sinars and from Sarkisov, et al.
- I(t) from Z with and without prepulse

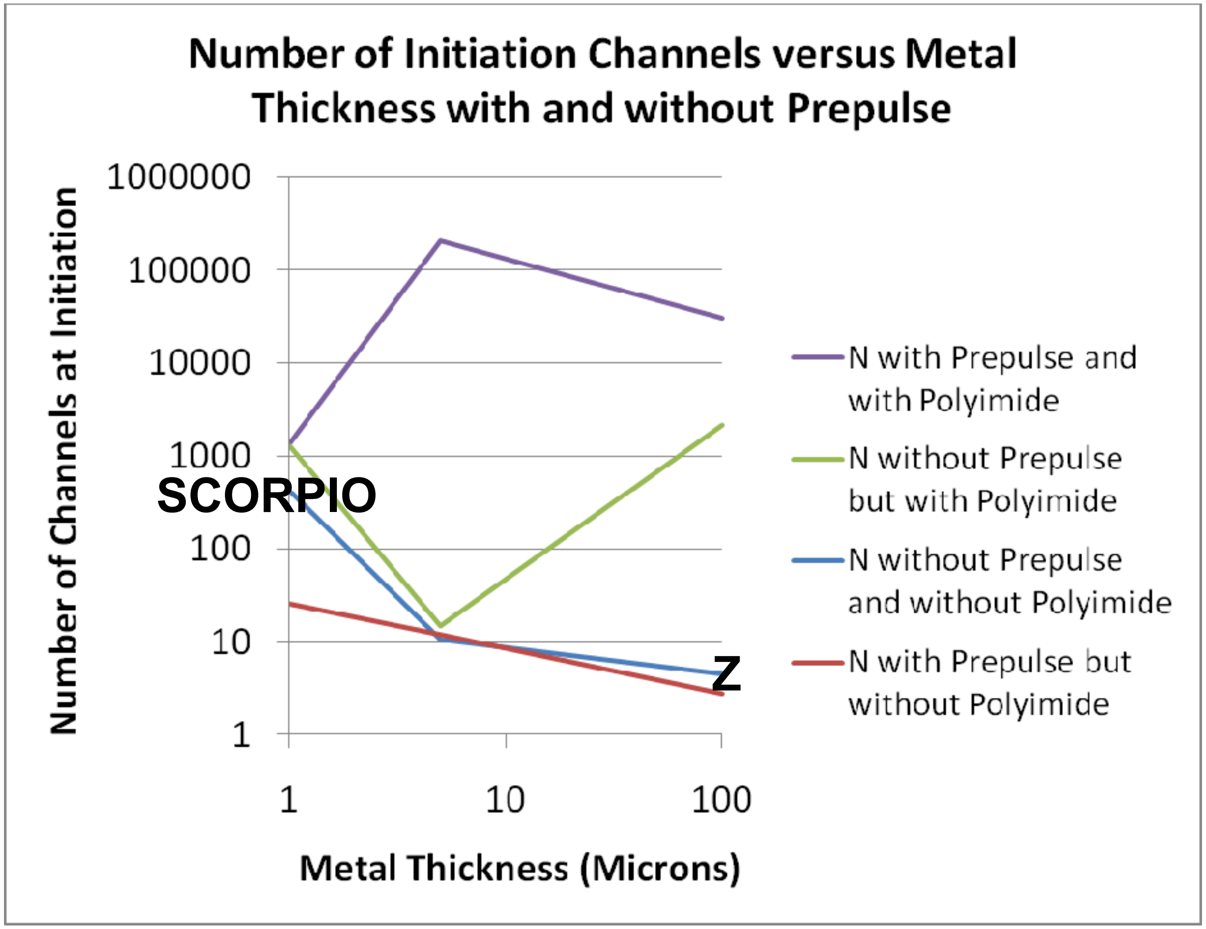


Computed number of channels indicates Z liners initiate in slow mode.

$\sigma(V)/V = 0.18\%$



Increasing σ(V)/V to 0.3 % gives a similar conclusion.



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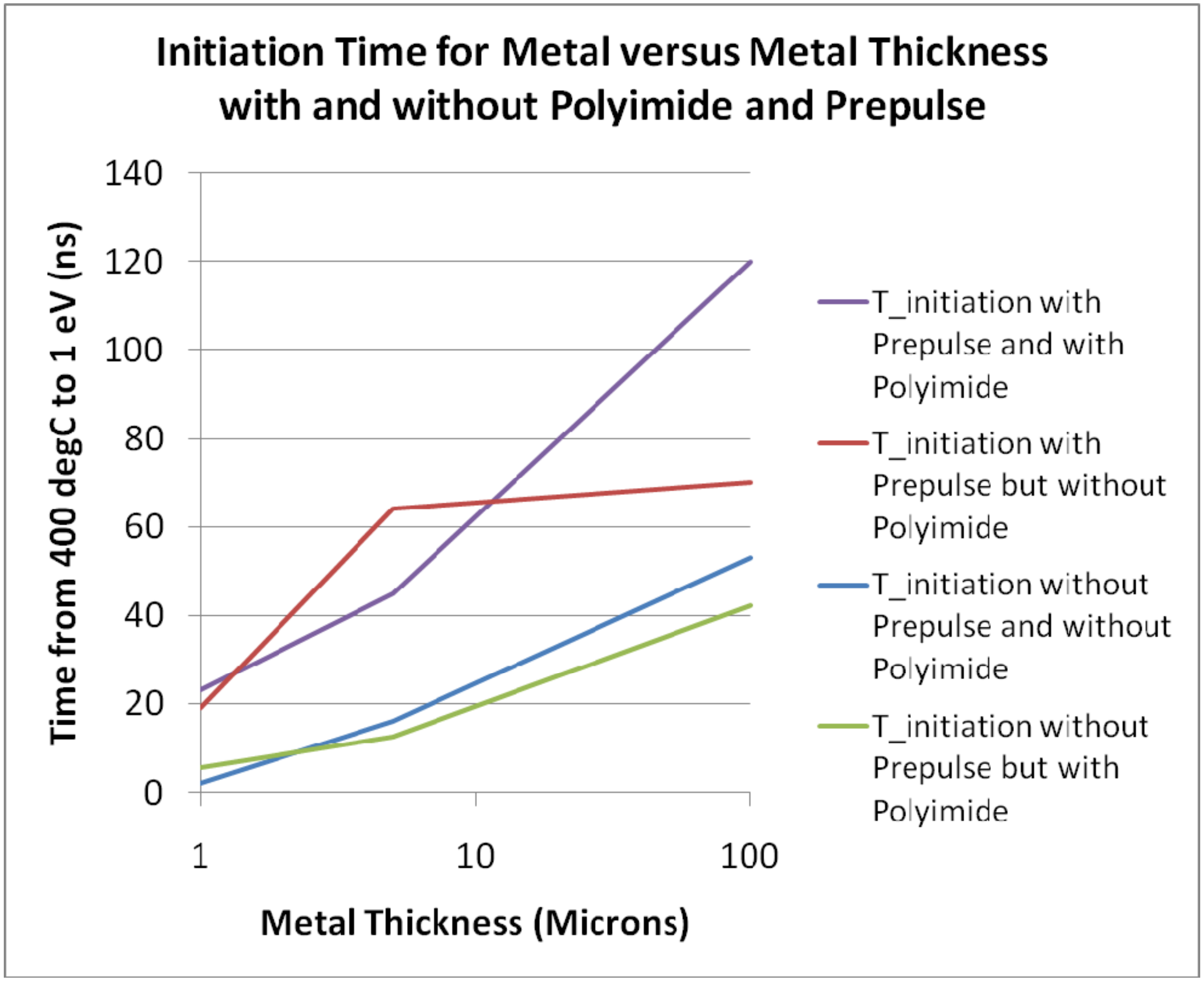
The calculations suggest a path forward.

- 5 microns Al works a bit better than 100 microns Al, but not as good as 1 micron
- 1 micron Al with 2 micron coating of polyimide gives best initiation
- Reduce prepulse—which is especially detrimental without polyimide
- Polyimide may be able to give adequate initiation even with prepulse and with 100 microns of Al—but this depends on LASNEX being right in an unusual application.

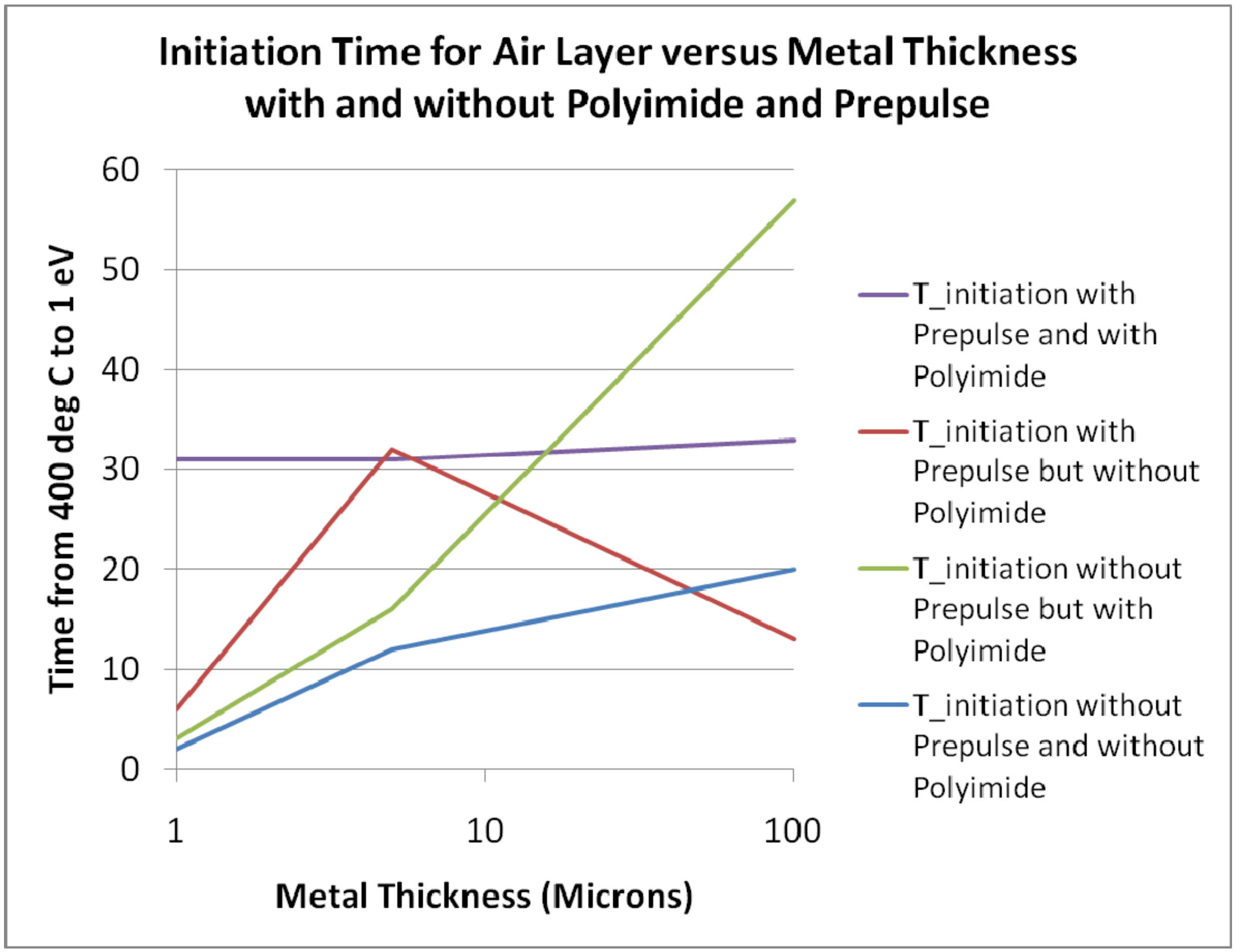
Backup Slides

Scorpio team and Mike Cuneo independently found >10ns requirement.



- Prepulse precludes <10 ns initiation
- Use 1 micron Al.
- Use 2 microns of polyimide—especially if we have to use 5 micron Al.

Gas initiation time <10 ns relies on LASNEX being right in unusual application.



- **1 micron Al is required.**
- **2 microns polyimide coating reduces risk**
- **If we have prepulse, polyimide coating may be insufficient.**

3 monolayer coating of air is modeled as hydrogen in 1D runs with LASNEX.

σ(V)/V = 0.18 %

Run	Thickness of Metal (microns)	Prepulse	Voltage across 2.5 mm	dV/dt (V/ns)	~ Half teff (ns) (time to peak only)	rho/rho(STP mmHg)	Metal Delta_t from 400 degC to 1 eV for Initiation (ns)	Air Layer Delta_t from 400 degC to 1 eV for Initiation (ns)	DeltaT (s)	N
Cyl1micAl	1	N	3.40E+04	14706	0.9	26.32	2	2	8.32E-12	1850
Cyl5micAl	5	N	2.10E+04	4348	3.5	0.84	16	12	1.74E-11	25
Cyl100micAl	100	N	1.80E+04	769	10	15.79	53	20	8.42E-11	15
Cyl1micAl	1	Y	3.20E+04	10000	1	3.53	19	6	1.15E-11	73
Cyl5micAl	5	Y	1.65E+04	1563	4	5.26	64	32	3.80E-11	41
Cyl100micAl	100	Y	1.65E+04	741	8	5.26	70	13	8.02E-11	7
Cyl1micAl_poly	1	N	1.00E+04	2000	1.5	10.53	5.7	3	1.80E-11	6000
Cyl5micAl_poly	5	N	1.50E+04	1176	4.5	7.89	12.5	16	4.59E-11	55
Cyl100micAl_poly	100	N	1255	93	11	0.42	42.4	57	4.84E-11	10000
Cyl1micAl_poly	1	Y	6.20E+03	1333	1.5	2.63	23	31	1.67E-11	6300
Cyl5micAl_poly	5	Y	500	20	13	2.63	45	31	9.00E-11	906000
Cyl100micAl_poly	100	Y	925	45	5	2.47	120	33	7.33E-11	135000
Cyl5micCu_poly	5	N	500	10	5	2.37	48	30	1.80E-10	103000
Cyl5micCu_poly	5	Y	500	10	5	2.37	47	33	1.80E-10	103000

Aluminum and copper conductors behaved somewhat differently in the details.

3 monolayer coating of air is modeled as hydrogen in 1D runs with LASNEX.

$\sigma(V)/V = 0.3\ \%$

Run	Thickness of Metal (microns)	Prepulse	Voltage across 2.5 mm	dV/dt (V/ns)	teff (ns)	rho/rho(STP mmHg)	Metal Delta_t from 400 degC to 1 eV for Initiation (ns)	Air Layer Delta_t from 400 degC to 1 eV for Initiation (ns)	DeltaT (s)	N
Cyl1micAl	1	N	3.40E+04	14706	0.9	26.32	2	2	1.39E-11	420
Cyl5micAl	5	N	2.10E+04	4348	3.5	0.84	16	12	2.90E-11	11
Cyl100micAl	100	N	1.80E+04	769	10	15.79	53	20	1.40E-10	5
Cyl1micAl	1	Y	3.20E+04	10000	1	3.53	19	6	1.92E-11	25
Cyl5micAl	5	Y	1.65E+04	1563	4	5.26	64	32	6.34E-11	12
Cyl100micAl	100	Y	1.65E+04	741	8	5.26	70	13	1.34E-10	3
Cyl1micAl_poly	1	N	1.00E+04	2000	1.5	10.53	5.7	3	3.00E-11	1300
Cyl5micAl_poly	5	N	1.50E+04	1176	4.5	7.89	12.5	16	7.65E-11	15
Cyl100micAl_poly	100	N	1255	93	11	0.42	42.4	57	8.07E-11	2150
Cyl1micAl_poly	1	Y	6.20E+03	1333	1.5	2.63	23	31	2.79E-11	1370
Cyl5micAl_poly	5	Y	500	20	13	2.63	45	31	1.50E-10	206000
Cyl100micAl_poly	100	Y	925	45	5	2.47	120	33	1.22E-10	30000
Cyl5micCu_poly	5	N	500	10	5	2.37	48	30	3.00E-10	22000
Cyl5micCu_poly	5	Y	500	10	5	2.37	47	33	3.00E-10	22000

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