Experiment on Metal Surface Damage Using 120 keV Beam

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Outline

- Motivation
- Experiment
- Reflection of electrons
- Pulse shortening
- Damage

Motivation

- **Model of rf breakdown damage limit**: arc electron currents heat bulk metal, metal surface melts and then ablates creating sources of new breakdowns.
- Simulation of breakdown predicts currents of ~1 kA with energy ~100 keV.

Idea: Simulate breakdown damage limit using pulsed 100 keV DC electron beam.

Advantage

•no high-precision machining
•no special metal’s surface processing
•no ultra-high vacuum
•can test many materials in short time

Experiment using electron welding machine

- Current :~20 mA
- Beam voltage:120 kV
- Pulse length :~70 μs
- We used electron beam repetition rate of 1 Hz
- We did not measure beam profile, but size of craters is ~200 micron

The welding machine has excellent sample's position control, beam focusing control an build-in microscope.

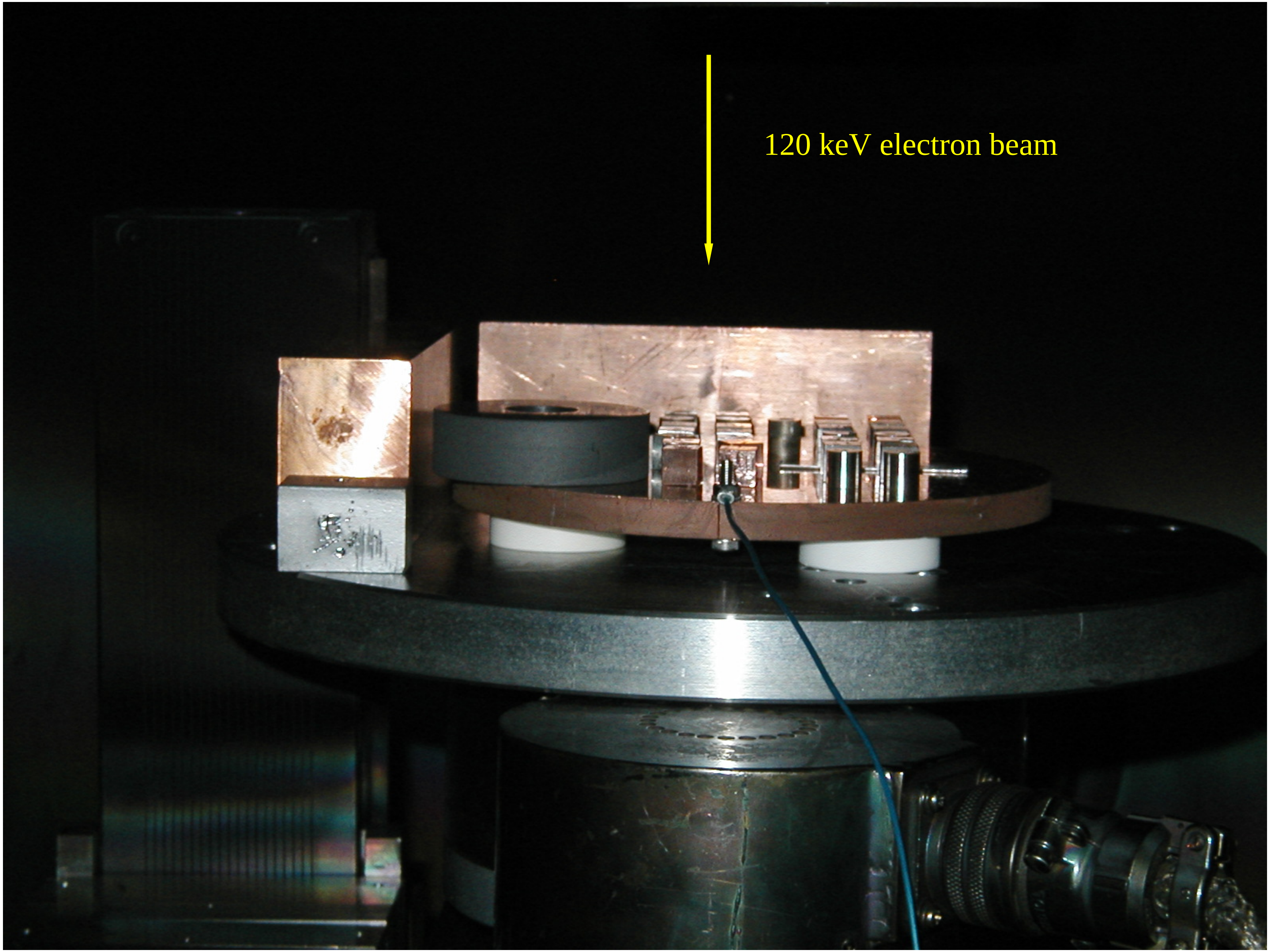
We note that main difference between parameters of this experiment and rf breakdown is the pulse length: 70 μs *vs*. 0.1 - 1 μs.

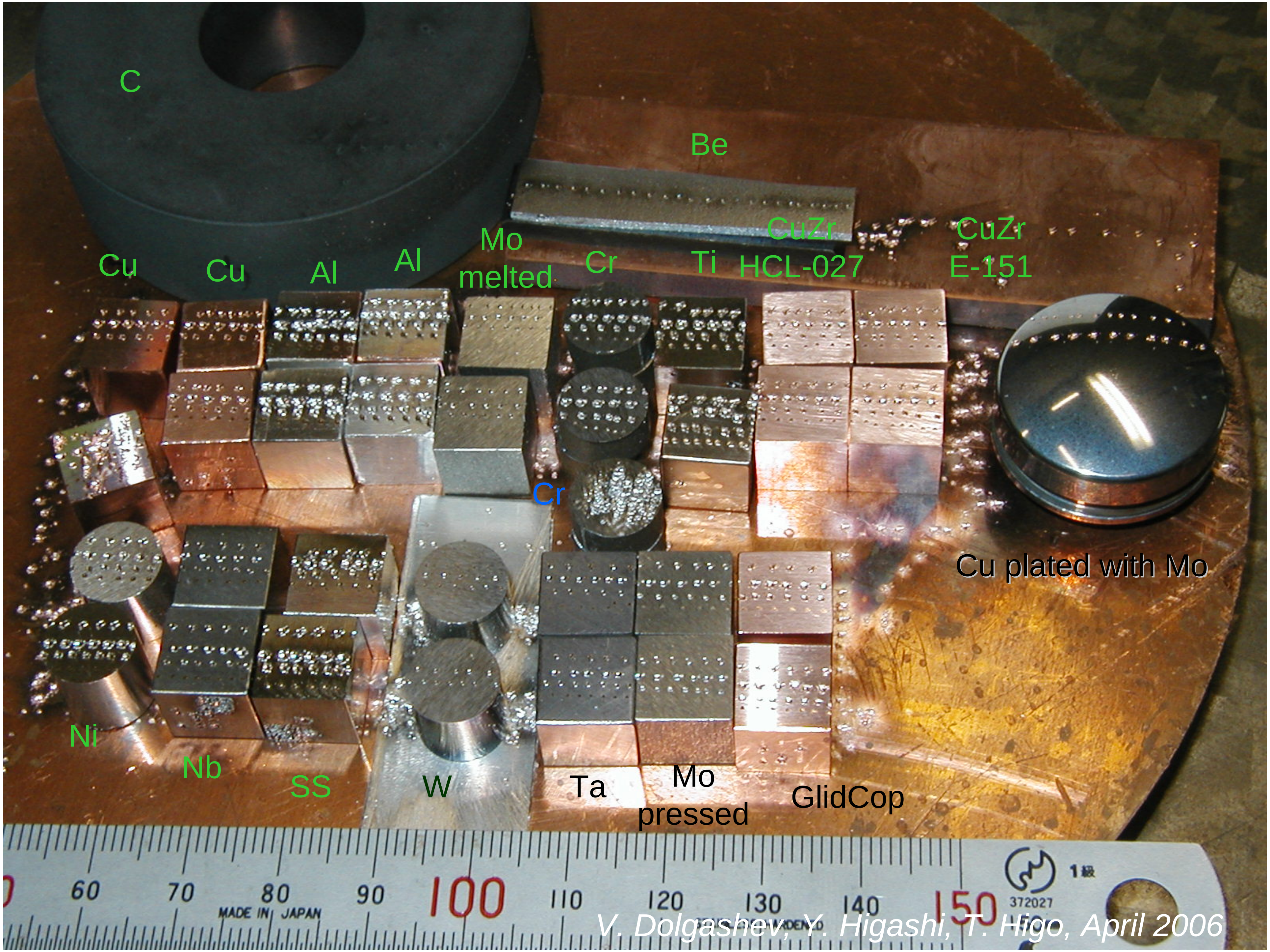

装置の種類
定格出力
責任者
斉藤商店


高 圧 電 源


電子光学銃


電子光学鏡
ワークチャンバー
制御盤本体


120 keV electron beam


C
Be
Cu
Cu
Al
Al
Mo
melted
Cr
Ti
CuZr
HCL-027
CuZr
E-151
Cr
Cu plated with Mo
Ni
Nb
SS
W
Ta
Mo
pressed
GlidCop
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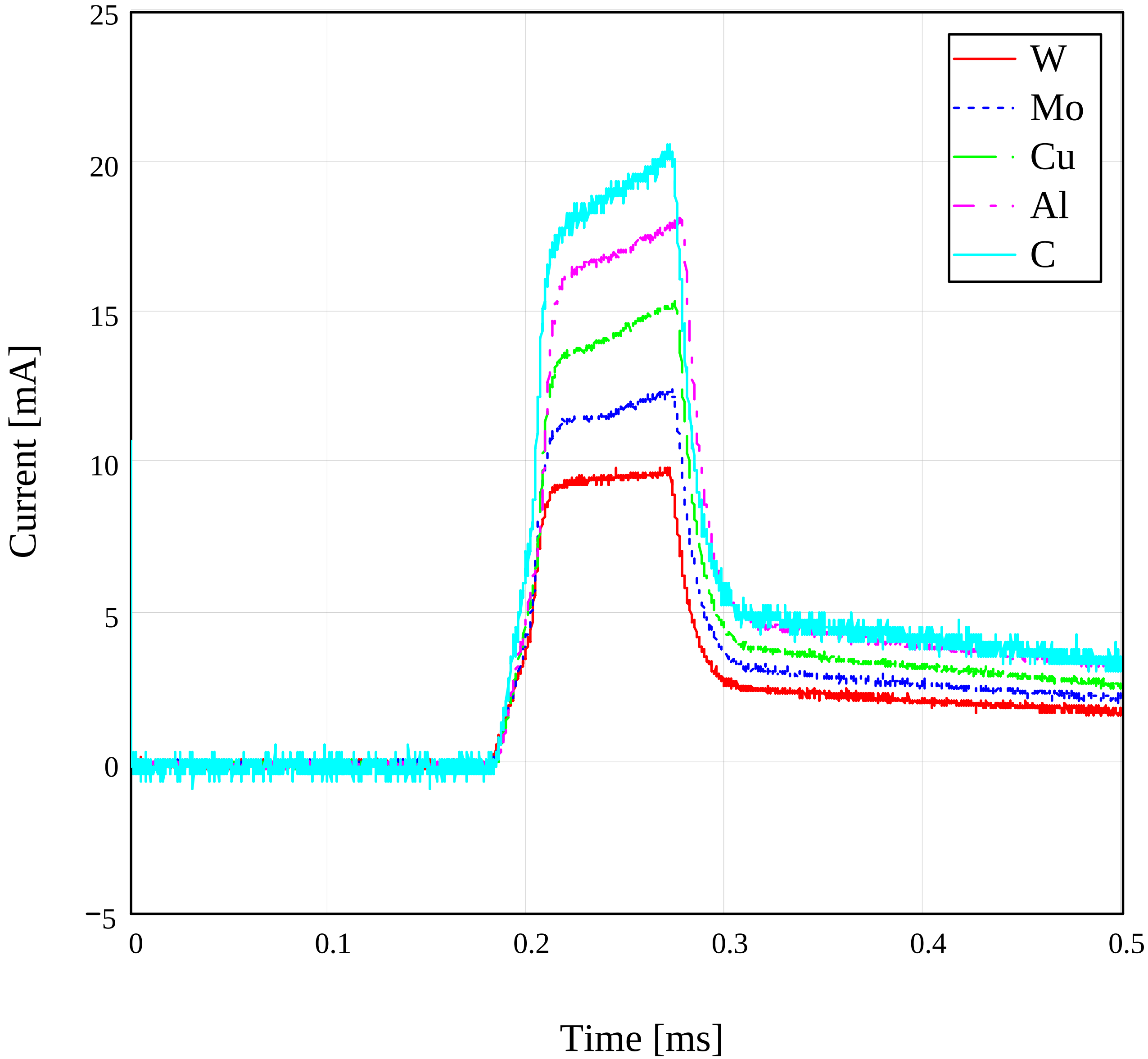
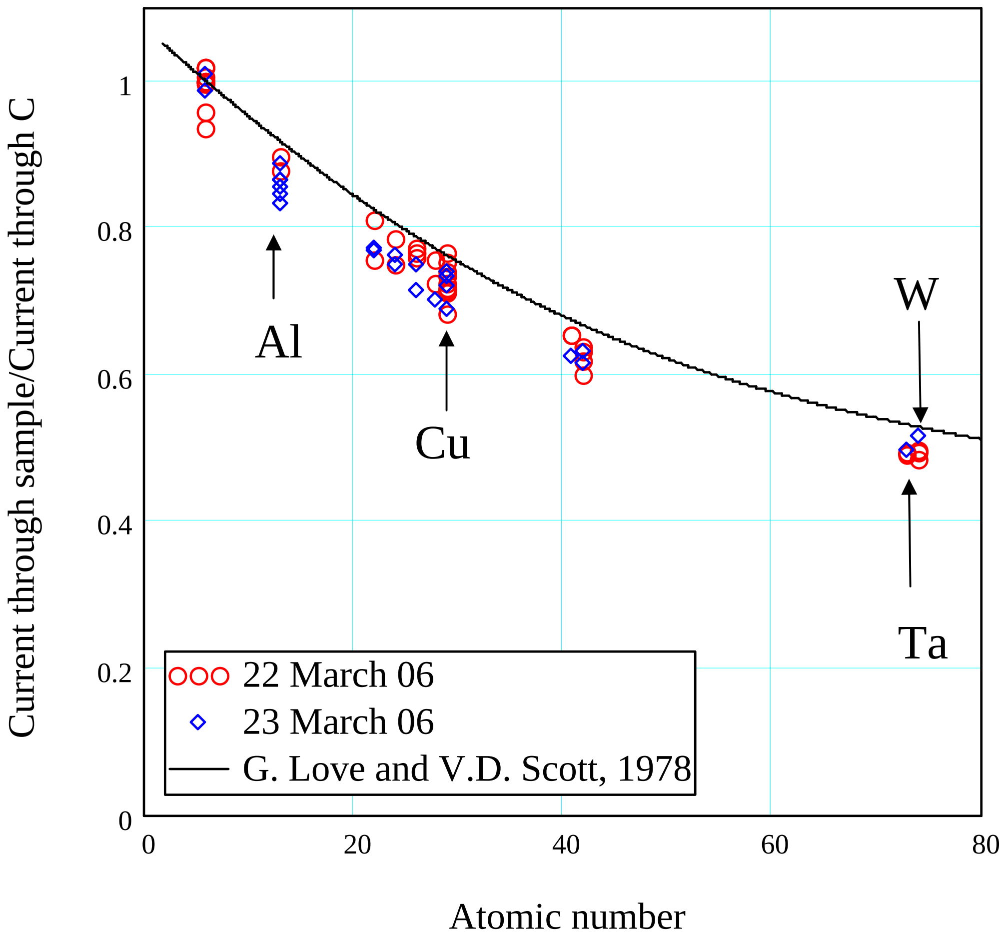
Reflection of electrons

Transmission of 120 kV current through different materials (data 22 March 06)



Transmission of 120 keV current through different metals normalized to carbon



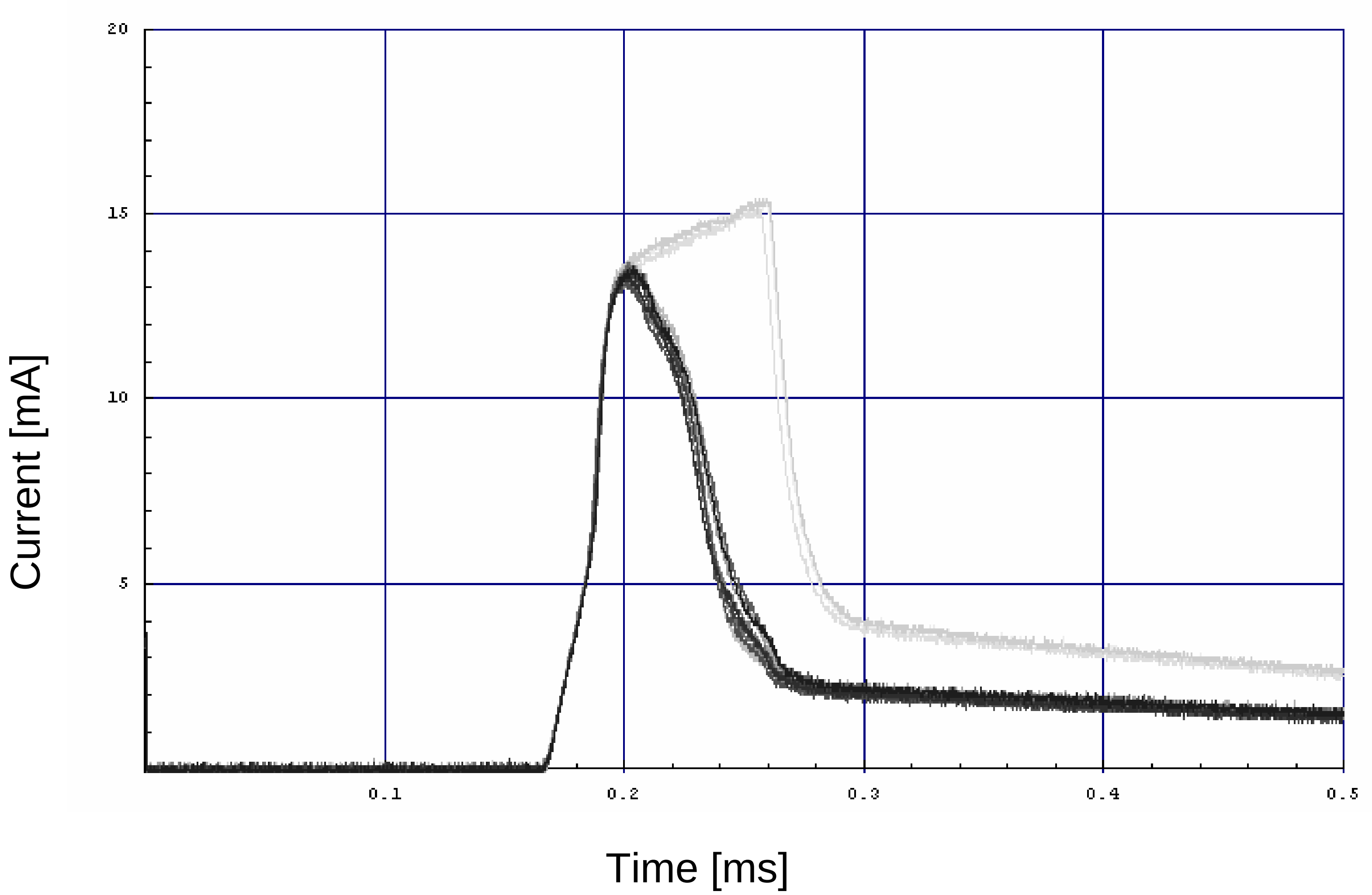
Solid curve: Love G and Scott V D 1978 ***J.*** *Phys. D: Appl. Phys.* 11 1369-76

Result

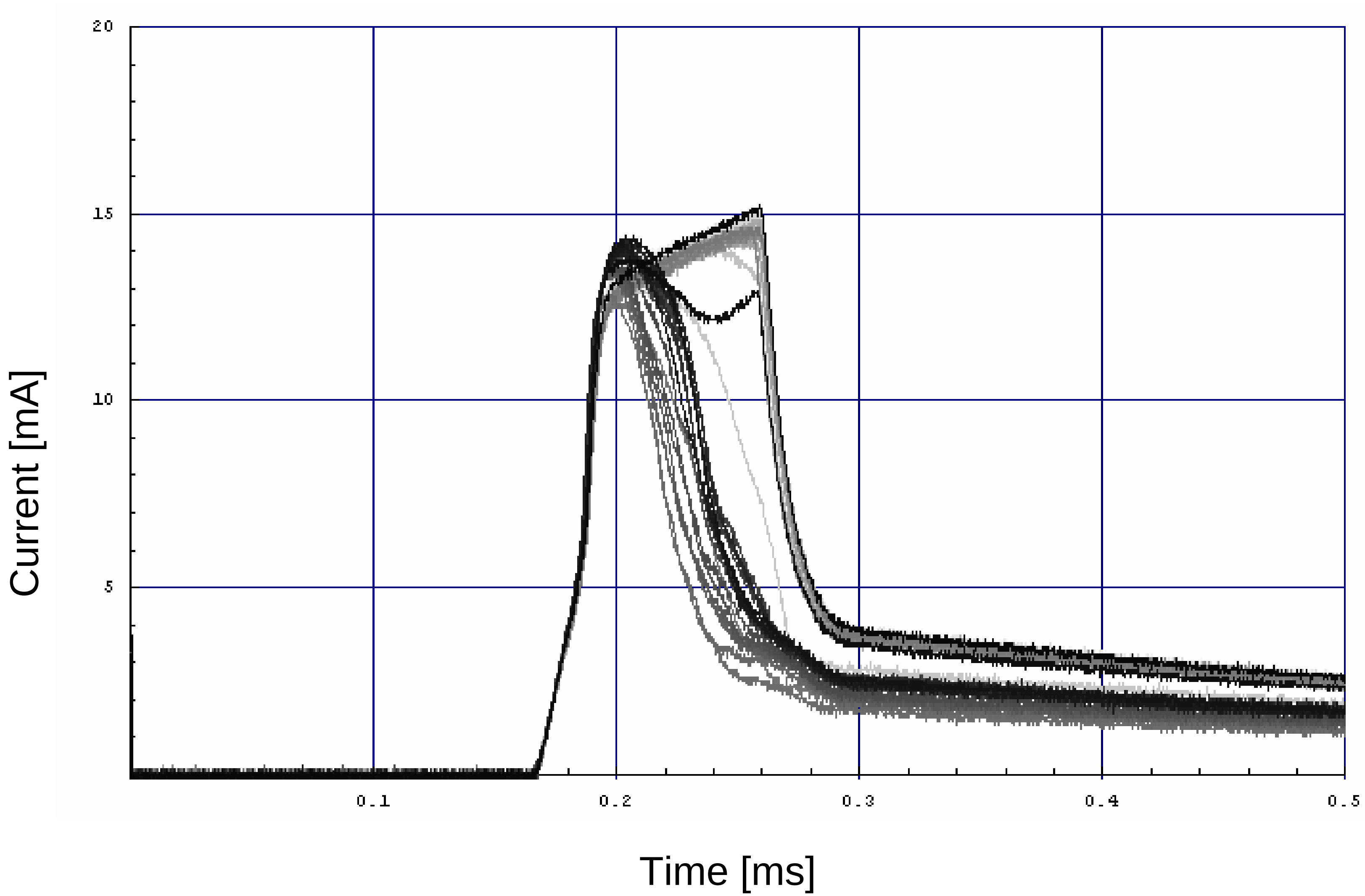
- Reflection is reasonably well predicted using atomic number and the beam voltage.
- Simulation of the breakdown damage should include reflection of electrons.

Pulse shortening

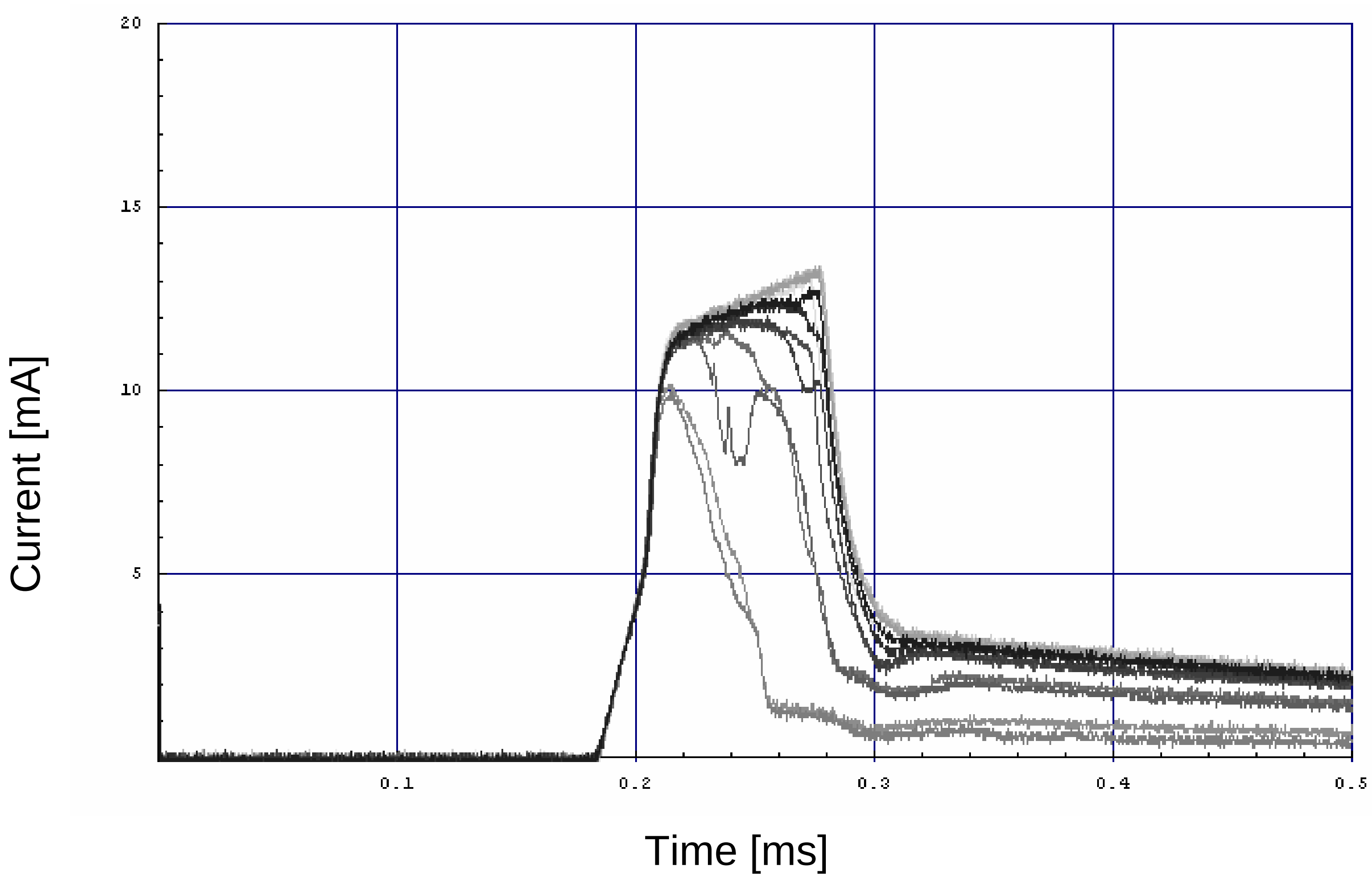
Pulse shortening in titanium (06-03-23-18-01-10)



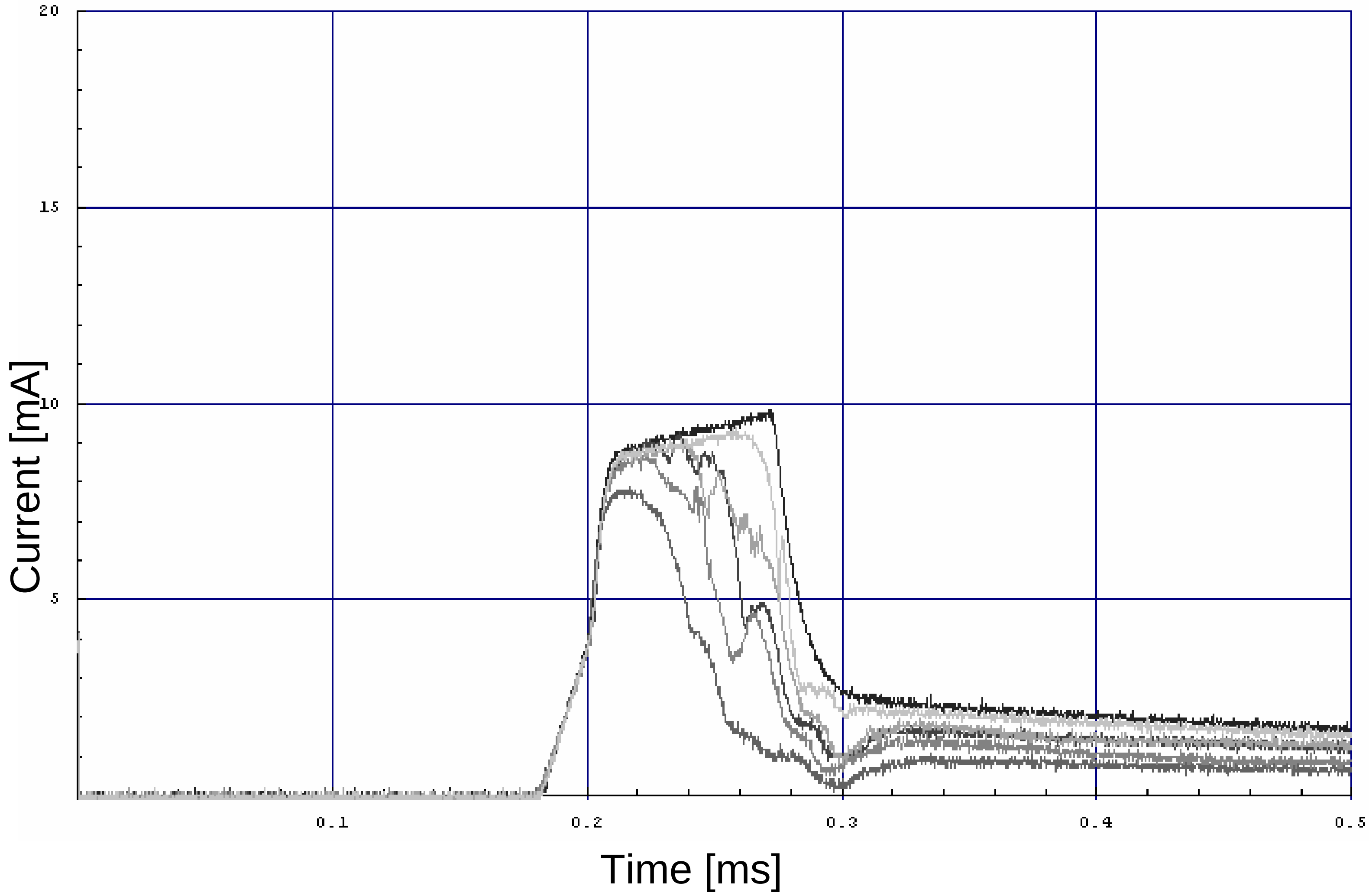
Pulse shortening in chromium (06-03-23-18-05-54)



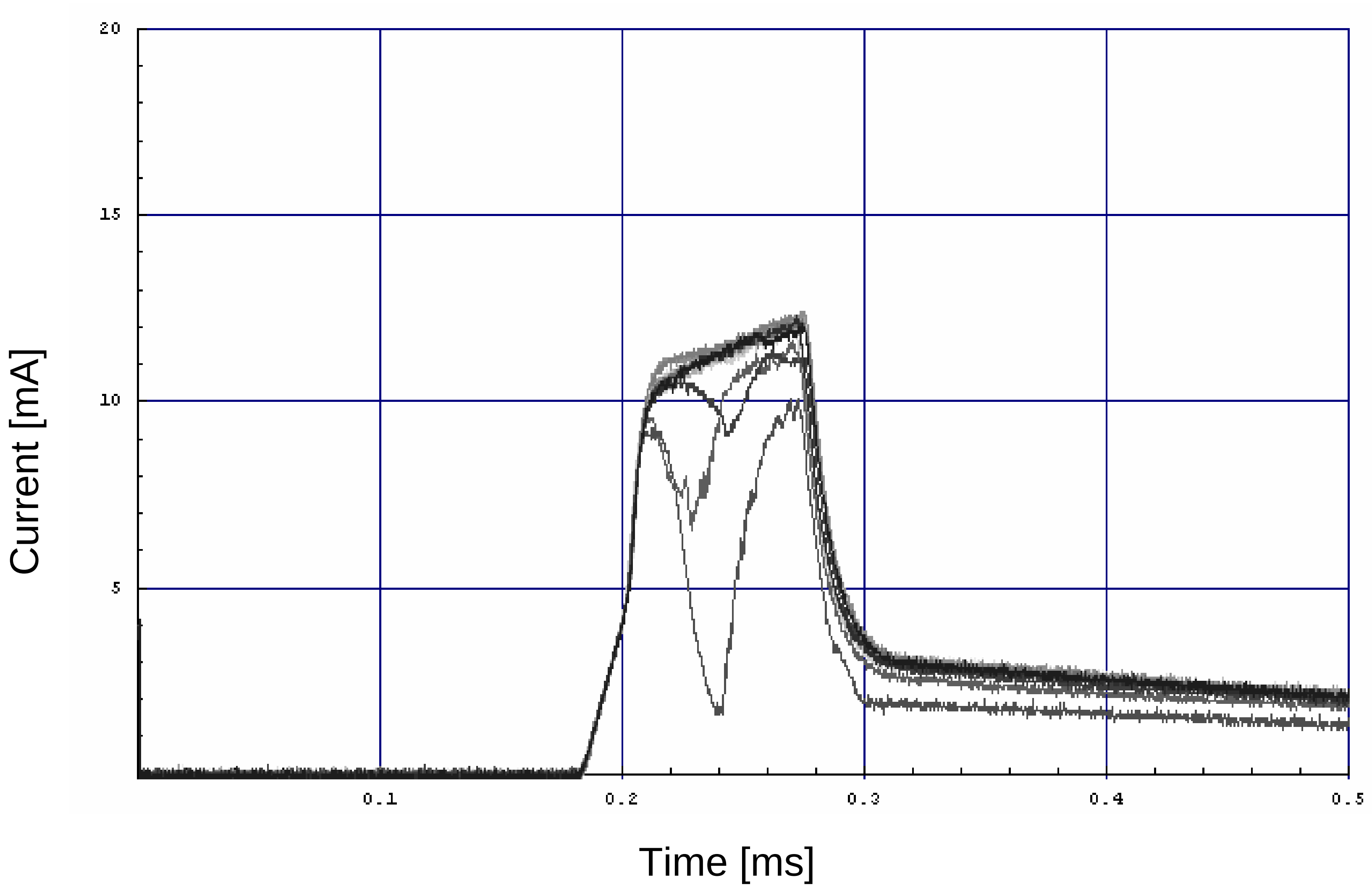
Pulse shortening in niobium (06-03-22-17-06-30)



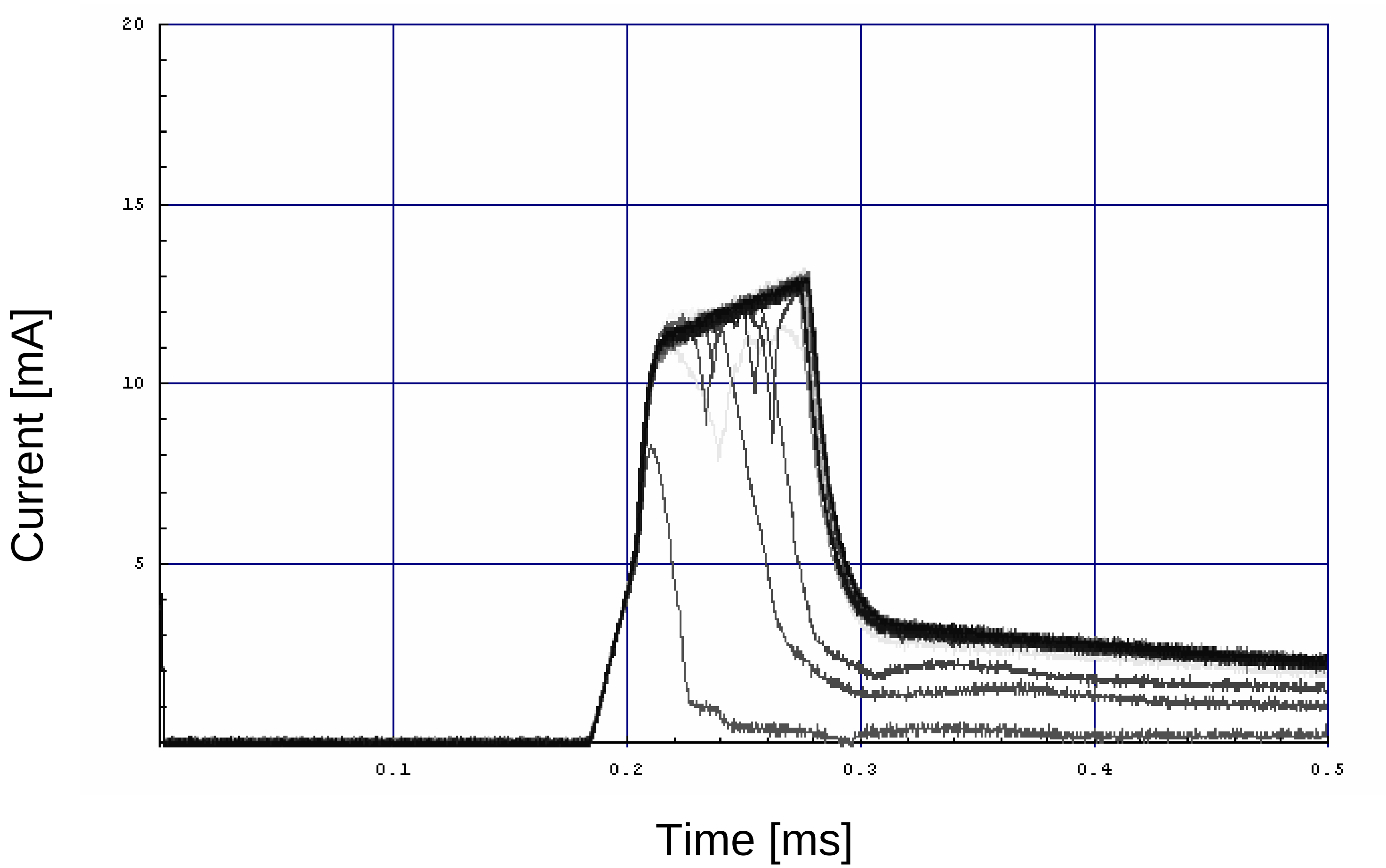
Pulse shortening in tungsten (06-03-22-18-15-50)



Pulse shortening in molybdenum re-melted (06-03-22-16-34-47)



Pulse shortening in molybdenum pressed (06-03-22-17-44-50)



Result

- For all metals we irradiated by beam with high density, after ~20 μs current flowing through the sample reduced – pulse shortens.
- This pulse shortening is reproducible from pulse to pulse.
- Physics of this pulse shortening as well as its relation to rf or DC breakdown is not clear and need more work to understand it.

Single shot damage of metal surface

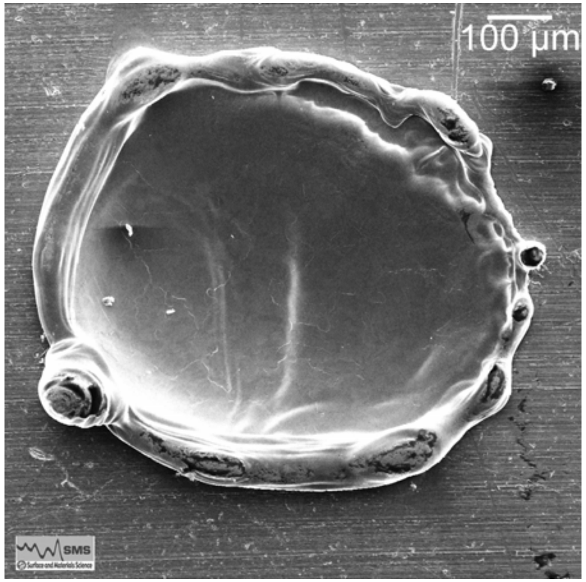
Method

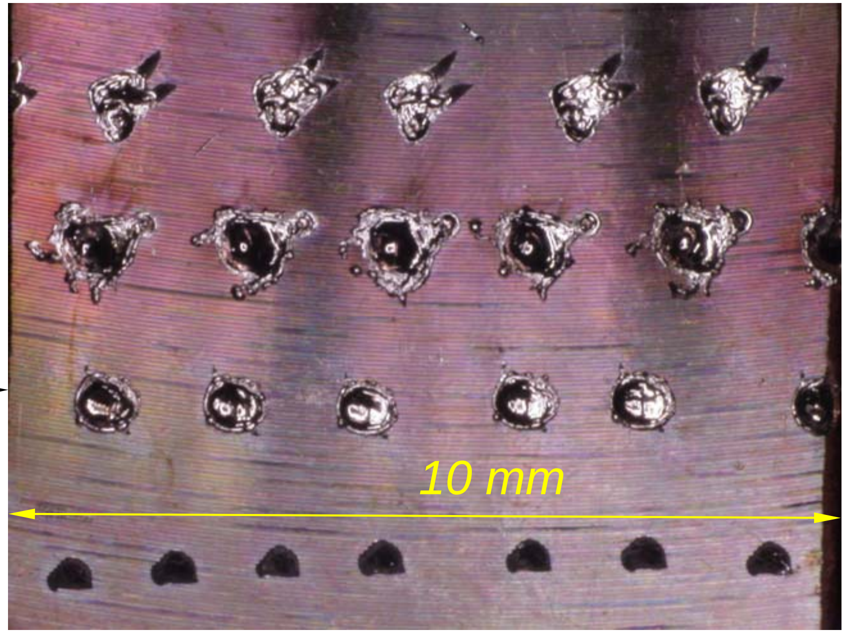
- Set beam focusing
- Irradiate all metals with 1 Hz repetition rate beam while moving sample, producing single craters with ~2 mm spacing
- Change focusing and repeat irradiation

We had 4 different focus settings, likely one over-focused and three under-focused one surface of the metals.

Optical and SEM pictures of copper and molybdenum

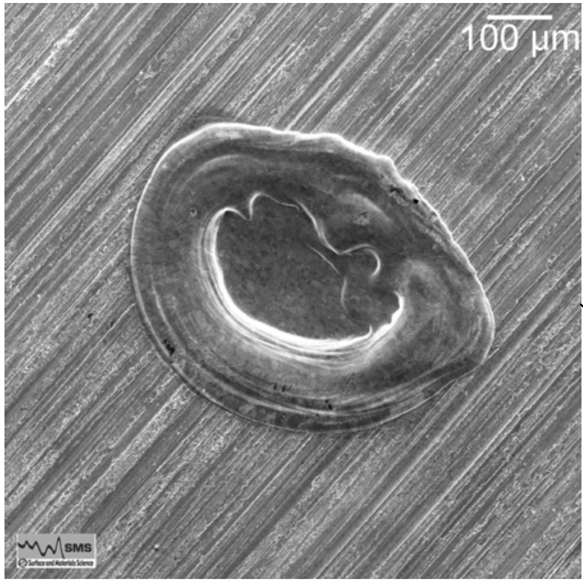
Copper



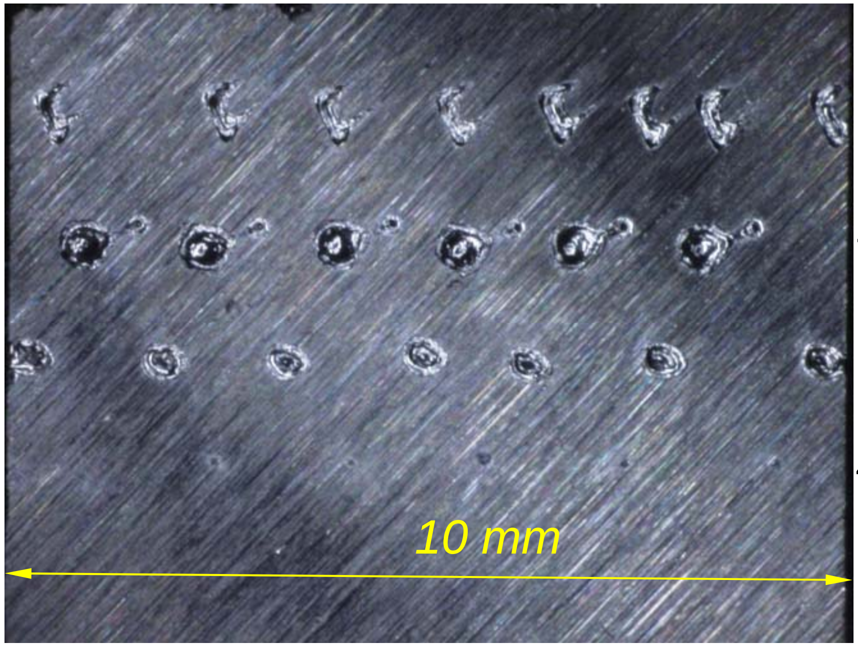


1st row
2nd row
3rd row

Moly



Bob Kirby



1st row
2nd row
3rd row
4th row

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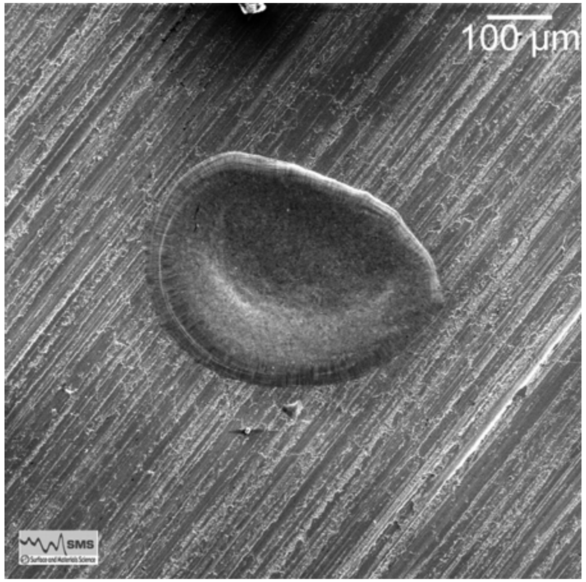
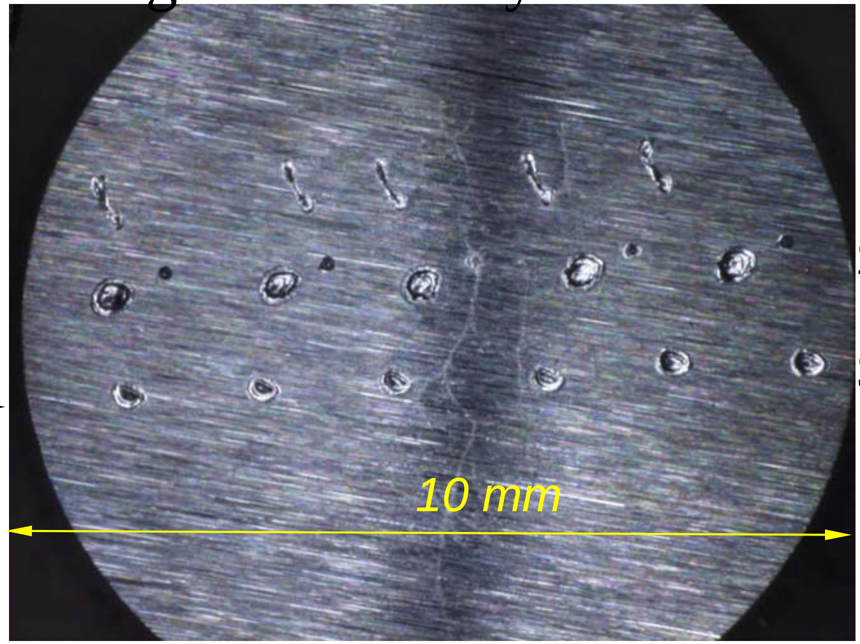
Optical and SEM pictures of tungsten and molybdenum

Tungsten



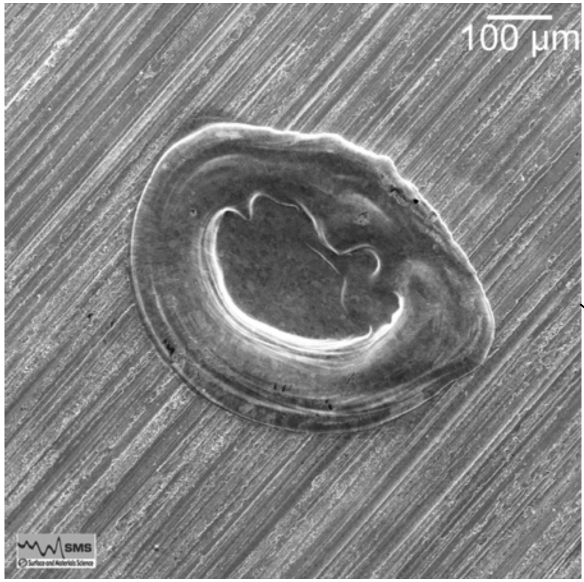


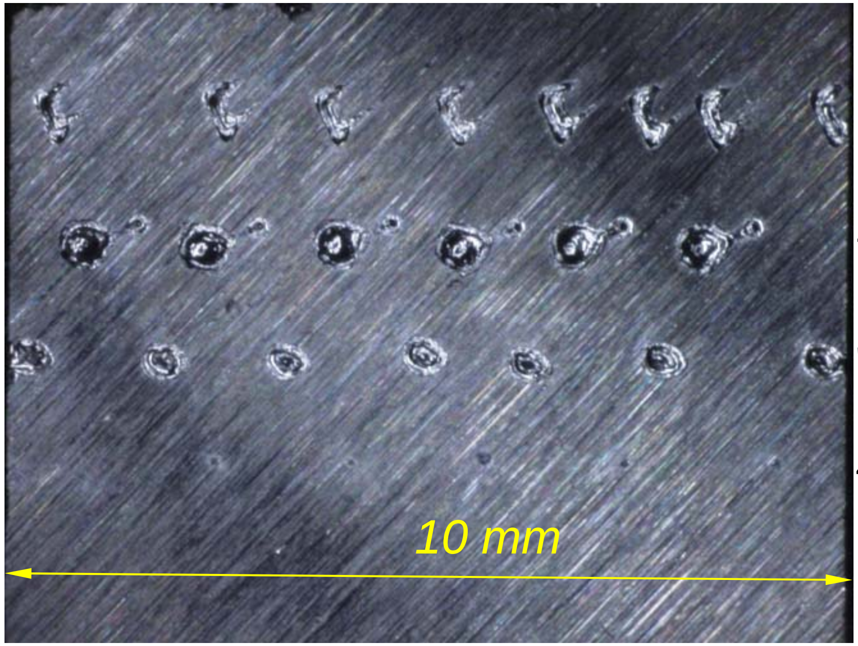
1st row

2nd row

3rd row

Moly





1st row

2nd row

3rd row

4th row

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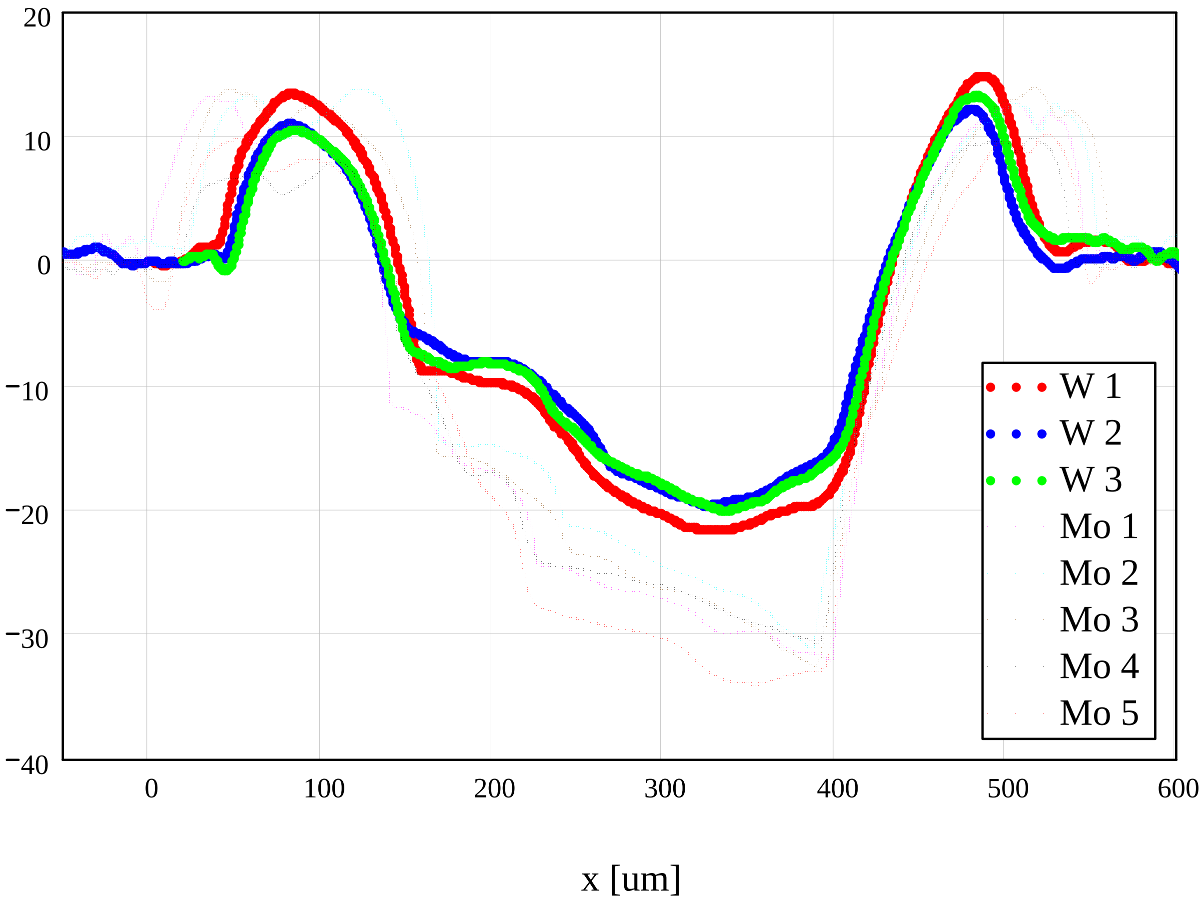
1D profile through middle of the spots in 3rd row for 8 different spots: 3 tungsten and 5 molybdenum



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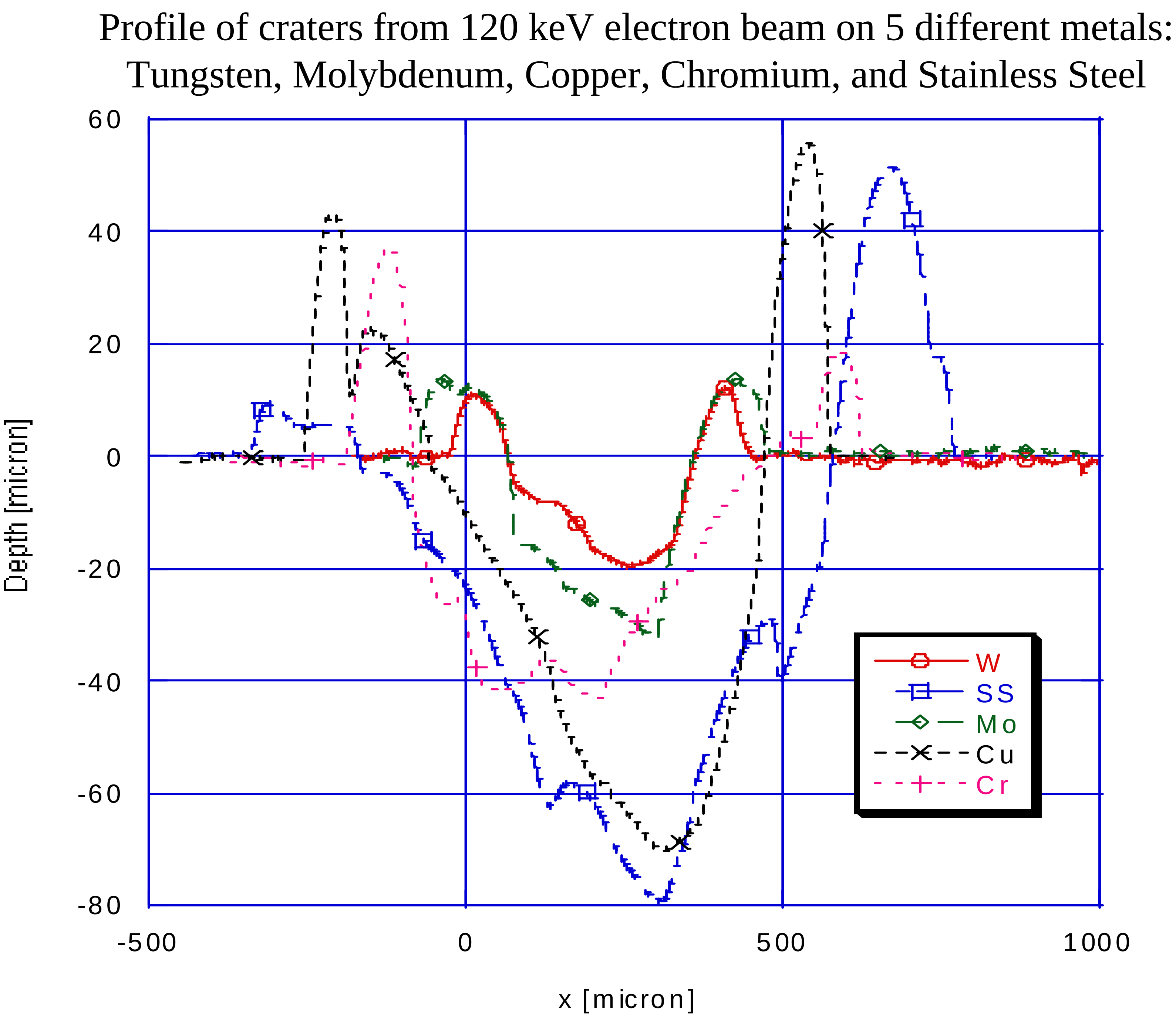
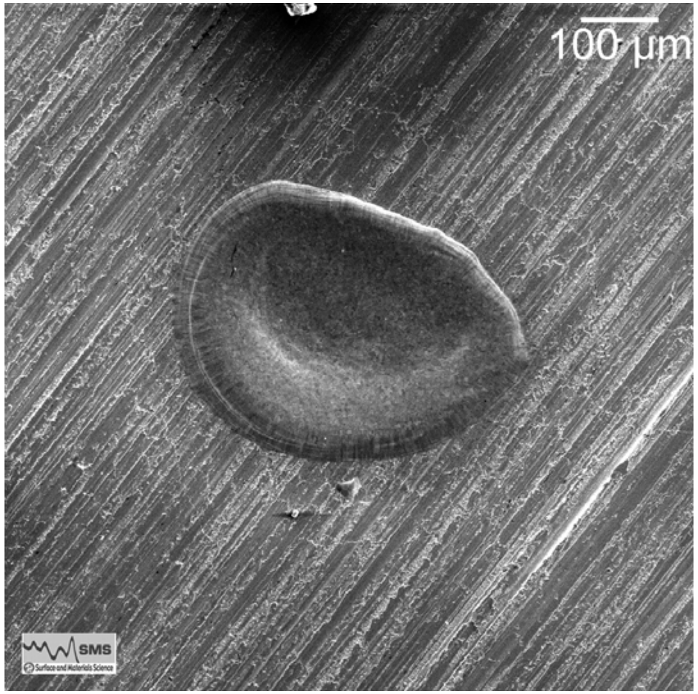

Profile of craters from 120 keV electron beam on 5 different metals:
Tungsten, Molybdenum, Copper, Chromium, and Stainless Steel
60
40
20
0
-20
-40
-60
-80
Depth [micron]
-500
0
500
1000
x [micron]
W
SS
Mo
Cu
Cr

Optical microscope images of beryllium and tungsten and SEM pictures of electron beam impact spots on tungsten



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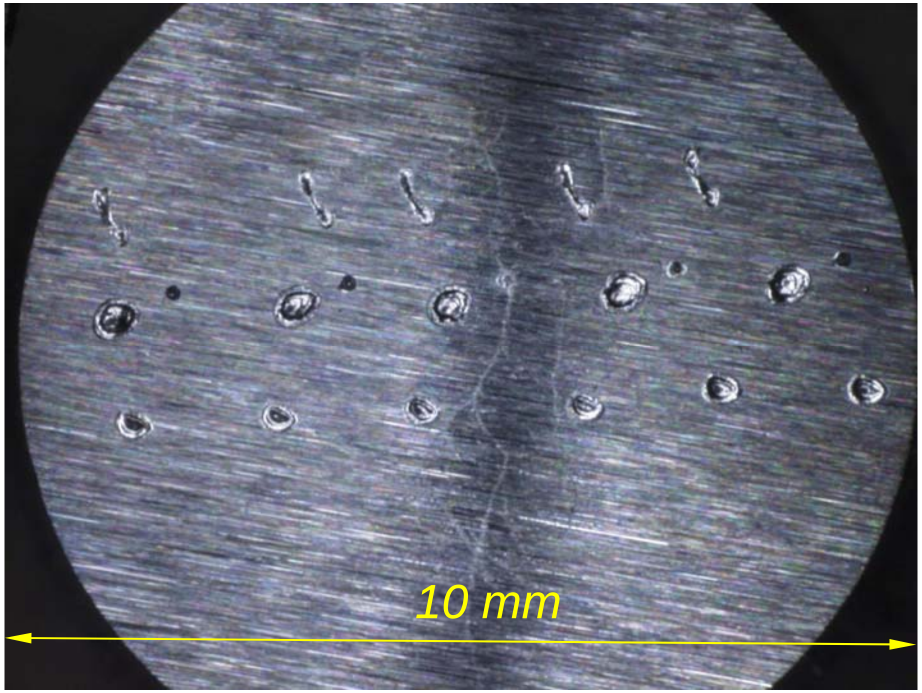
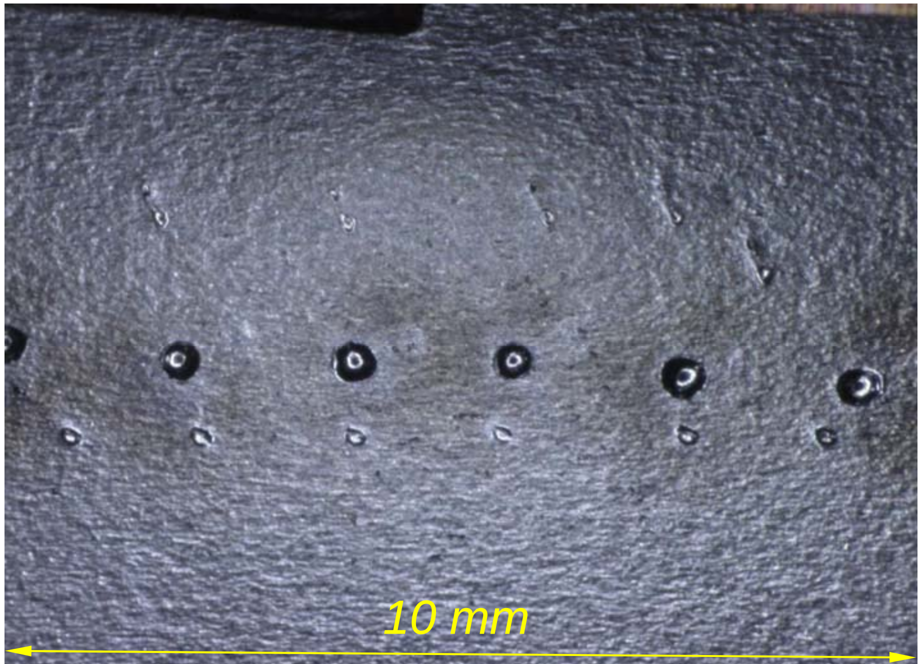
Tungsten



Beryllium



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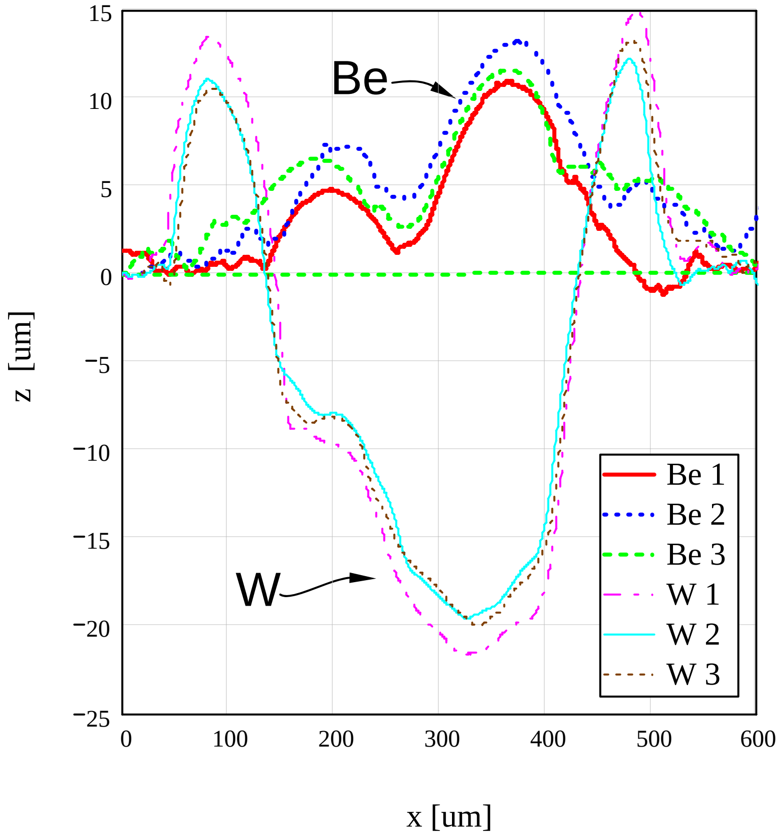
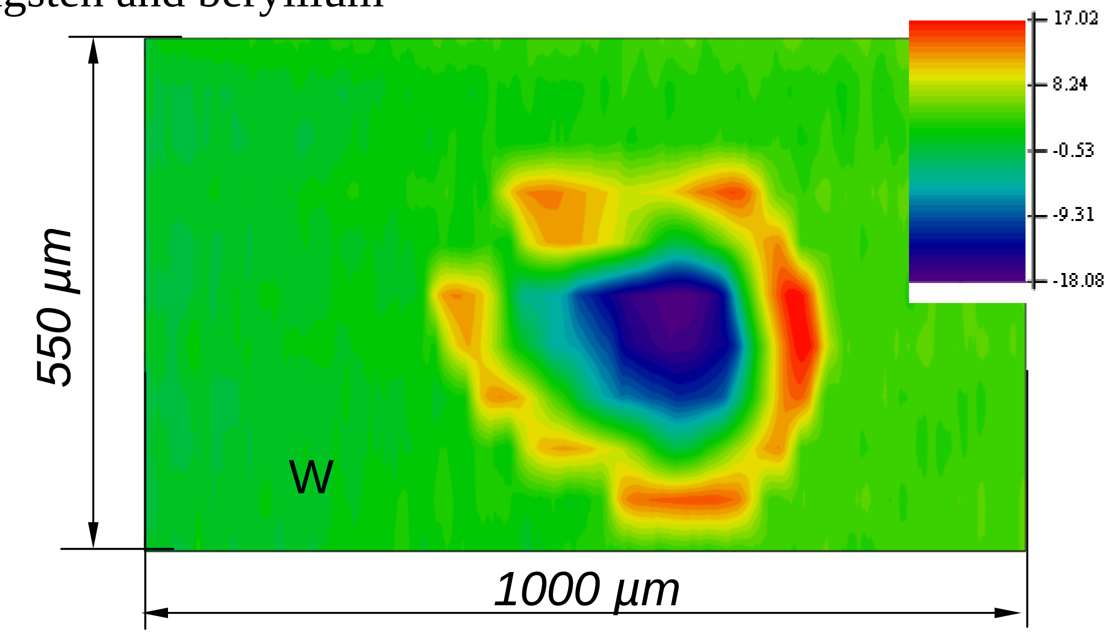
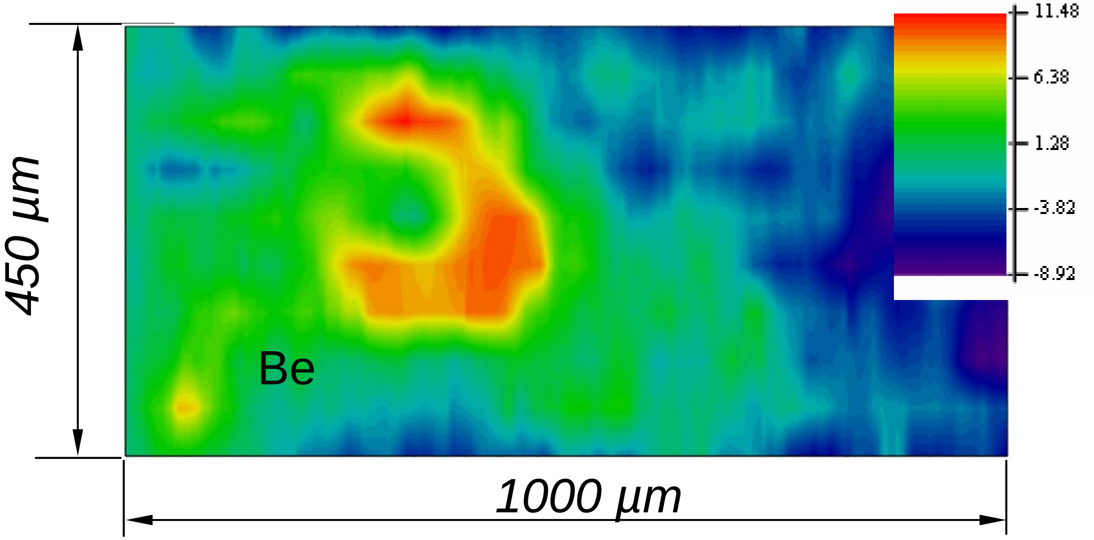
Profile measurements of impact spot of 120 kV electron beam with same power density for tungsten and beryllium



1D profile
through middle of the spot
for 6 different spots:
3 beryllium and 3 tungsten.





2D profile

Profiles measured using Dektak Bench-Top Surface Profiler

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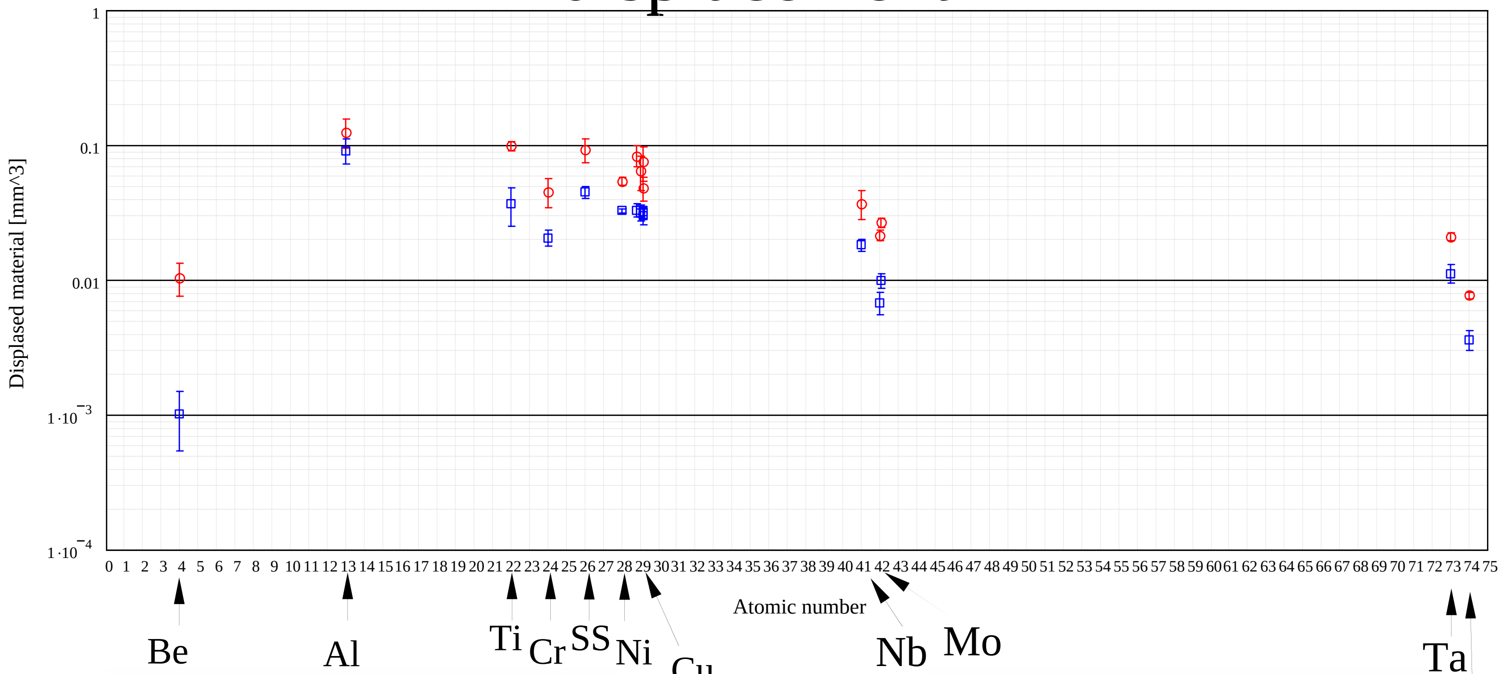
Characterization of damage by amount of material displacement



3rd damage Trace, less damage

	0	1
0	"Be"	$1.01673\cdot10^{-3}$
1	"W"	$3.58224\cdot10^{-3}$
2	"Mo_mlt"	$6.70994\cdot10^{-3}$
3	"Mo_pr"	$9.8665\cdot10^{-3}$
4	"Ta"	$1.11645\cdot10^{-2}$
5	"Nb"	$1.81326\cdot10^{-2}$
6	"Cr"	$2.04191\cdot10^{-2}$
7	"CuZr_HCL027"	$2.95816\cdot10^{-2}$
8	"Cu"	$3.14926\cdot10^{-2}$
9	"CuZr_C151"	$3.1711\cdot10^{-2}$
10	"Ni"	$3.24132\cdot10^{-2}$
11	"GlidCop"	$3.29924\cdot10^{-2}$
12	"Ti"	$3.67915\cdot10^{-2}$
13	"SS"	$4.46869\cdot10^{-2}$
14	"Al"	$9.13197\cdot10^{-2}$

2nd damage Trace, more damage

	0	1
0	"W"	$7.704\cdot10^{-3}$
1	"Be"	$1.029\cdot10^{-2}$
2	"Ta"	$2.093\cdot10^{-2}$
3	"Mo_mlt"	$2.138\cdot10^{-2}$
4	"Mo_pr"	$2.666\cdot10^{-2}$
5	"Nb"	$3.694\cdot10^{-2}$
6	"Cr"	$4.503\cdot10^{-2}$
7	"CuZr_HCL027"	$4.791\cdot10^{-2}$
8	"Ni"	$5.411\cdot10^{-2}$
9	"Cu"	$6.396\cdot10^{-2}$
10	"CuZr_C151"	$7.485\cdot10^{-2}$
11	"GlidCop"	$8.334\cdot10^{-2}$
12	"SS"	$9.214\cdot10^{-2}$
13	"Ti"	$9.847\cdot10^{-2}$
14	"Al"	0.125

Result

- **Be** is least damaged by electron beam, **W** is next least damage material
- High atomic number elements (from **Nb** and higher) has less damage then **Cu**
- **Cr** has less damage then **Cu**
- **Cu, CuZr** and **GlidCop** have very similar damage to **Cu**
- **Ti, SS,** and **Al** have more damage then **Cu**
- For materials ordered by amount of damage, the order changes with increased beam density.

- We note that breakdown limit for **SS** in waveguide experiment was higher then that of **Cu**

Summary

- **Beryllium** is a metal most resistant to damage by 120 keV electron beam.
- We need to establish relation between result of this experiment and rf breakdown damage limits.

- This test setup may be unique tool to study damage in complex materials: platings, coatings, bondings, multilayered materials, metals on dielectrics, dielectrics on metals *etc*.

“Perfect” material

- High meting temperature, low atomic number foil with high conductivity (couple of skin depth thick).