IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), July 2015.
Invited presentation M1OrC-01 given at CEC-ICMC 2015, Tucson, USA, June 28 – July 2, 2015.

Effectiveness of laser striation for AC loss reduction in SuperOx coated conductor

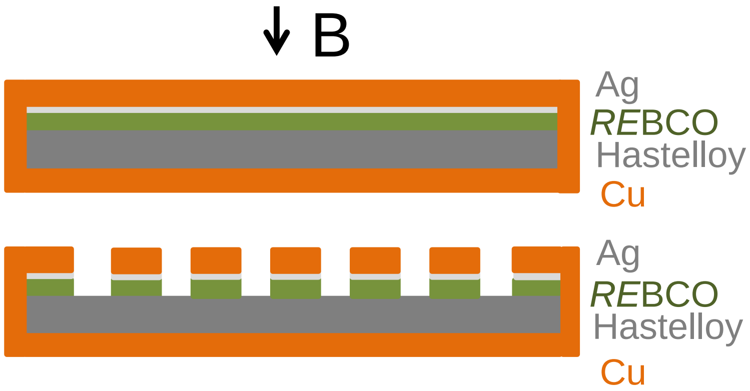
A. Kario, R. Nast, A. Jung, B. Ringsdorf, E. Demenčík, B. Runtsch, A. Godfrin, R. Gyuraki, F. Grilli, W. Goldacker (KIT, ITEP)

A. Molodyk, A. Mankevich (SuperOx)

J. Scheiter (IFW Dresden)

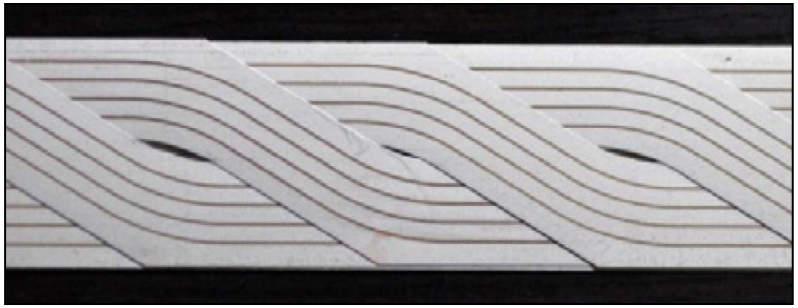
Karlsruhe Institute of Technology

Striations reduce magnetisation AC losses:



- Filament structures in CC is a way to reduce AC losses:
  - AC loss is proportional to the conductor squere width
  - introducing N filaments the losses are reduced by a factor N

- Striation require sophisticated material processing:
  - Methods: Laser scribing, chemical etching, Mechanical scribing, inject printing.
  - Technical CC require stabilisation.
  - Up to now a lot of work done on Ag-cap conductors.



Roebel Assembled Coated Conductor Cable with filaments

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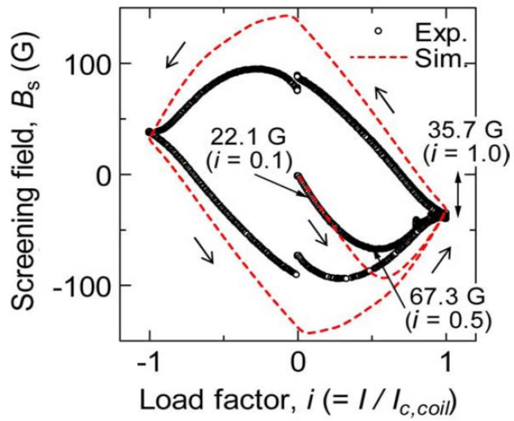
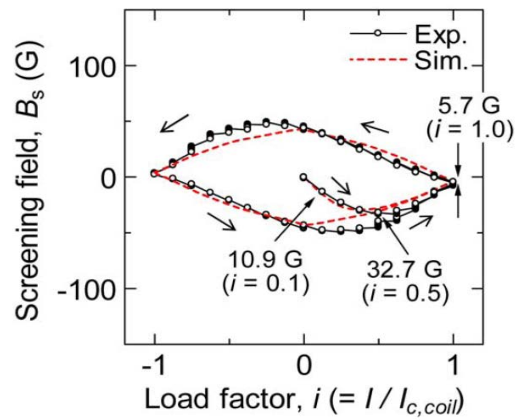
Striations reduce AC magnetisation losses:

Pancake coil:

monofilament



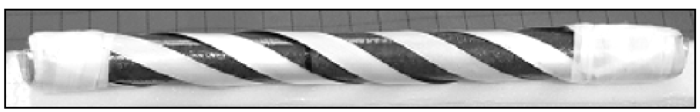
3 filaments



- *RE*BCO SuperPower
- 27x2 turns
- 16.8 m tape
- $B_{s,Coil\text{-}B}/B_{s,Coil\text{-}A}$ is 49%

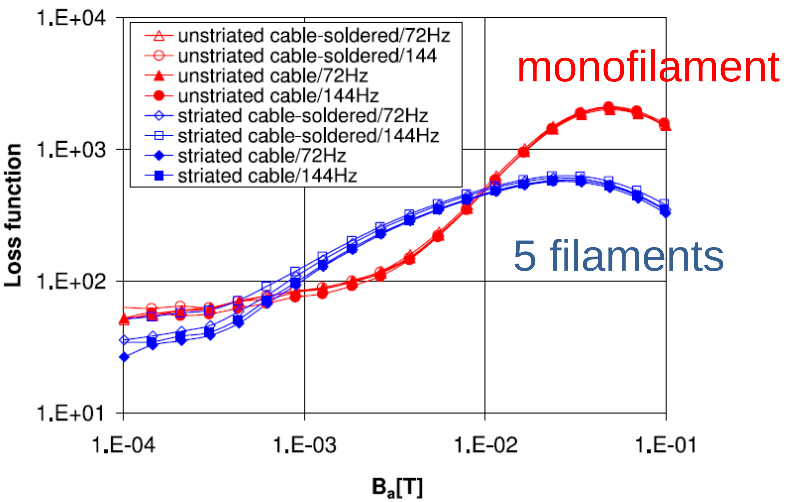
Y. Yanagisawa et al., IEEE Transactions on Applied Superconductivity, Vol. 25, No. 3, June 2015

CORC cabel IEE Bratislava:



- 2 cables: monofilament and 5 filaments
- *RE*BCO Ag SuperPower 4 mm
- tape lay pitch 50 mm
- length of cable model 100 mm

J. Souc et al., Supercond. Sci. Technol. 26 (2013) 075020 (5pp)



Two different structuring approaches used:

SuperOx

Laser cutting

5 µm Cu — 5 Watt / 50 passes

10 µm Cu — 5 Watt / 60 passes

- 0-120 Filaments
- 12 mm width

Ag — Laser cutting, 5 Watt / 10 passes

- Oxidation (500°C / 1h)
- Cu plating

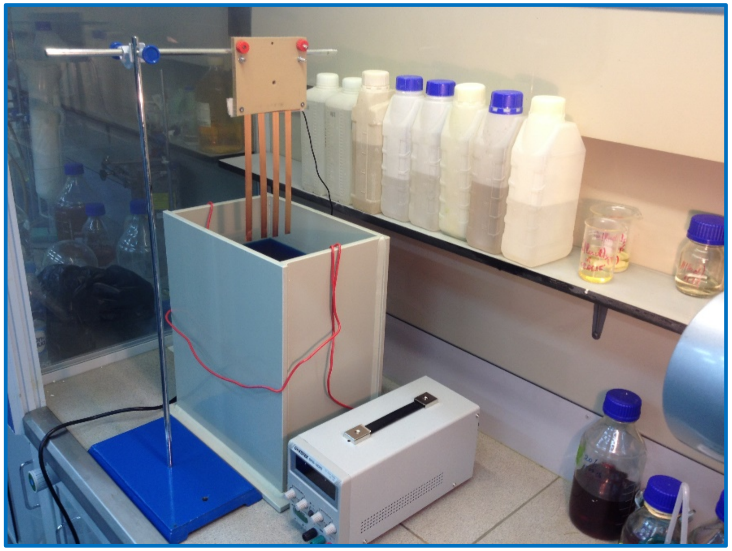
5 µm Cu

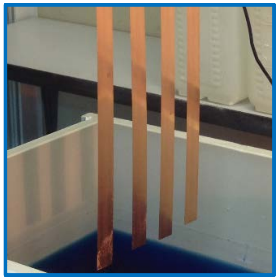
7 µm Cu

10 µm Cu

- 0- 60 Filaments
- 12 mm width

Electroplating process at SuperOx:





Short tapes

- Static batch process
- Plating time: 5 μm Cu: 6 min
  7 μm Cu: 8,5 min
  10 μm Cu: 12 min

Long tapes

- Continuous reel-to-reel process
- Tape speed: 5 μm Cu: 200 m/h
  10 μm Cu: 100 m/h

A. Molodyk ''Production and integration of 2G HTS tapes into HTS devices'' Tuesday M2OrC

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Laser filaments of the different tapes:

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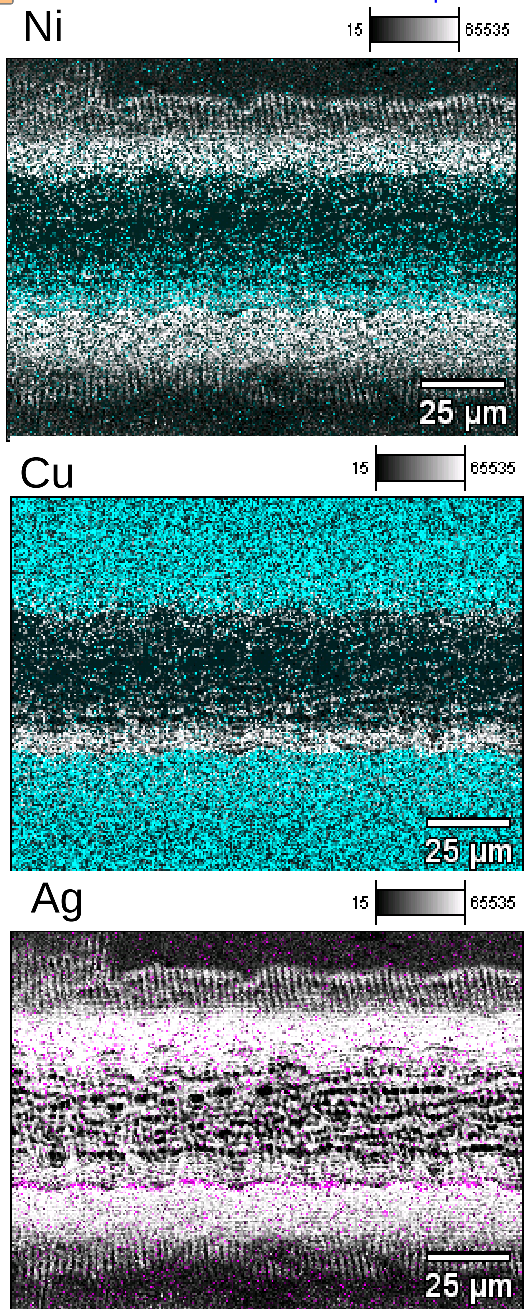
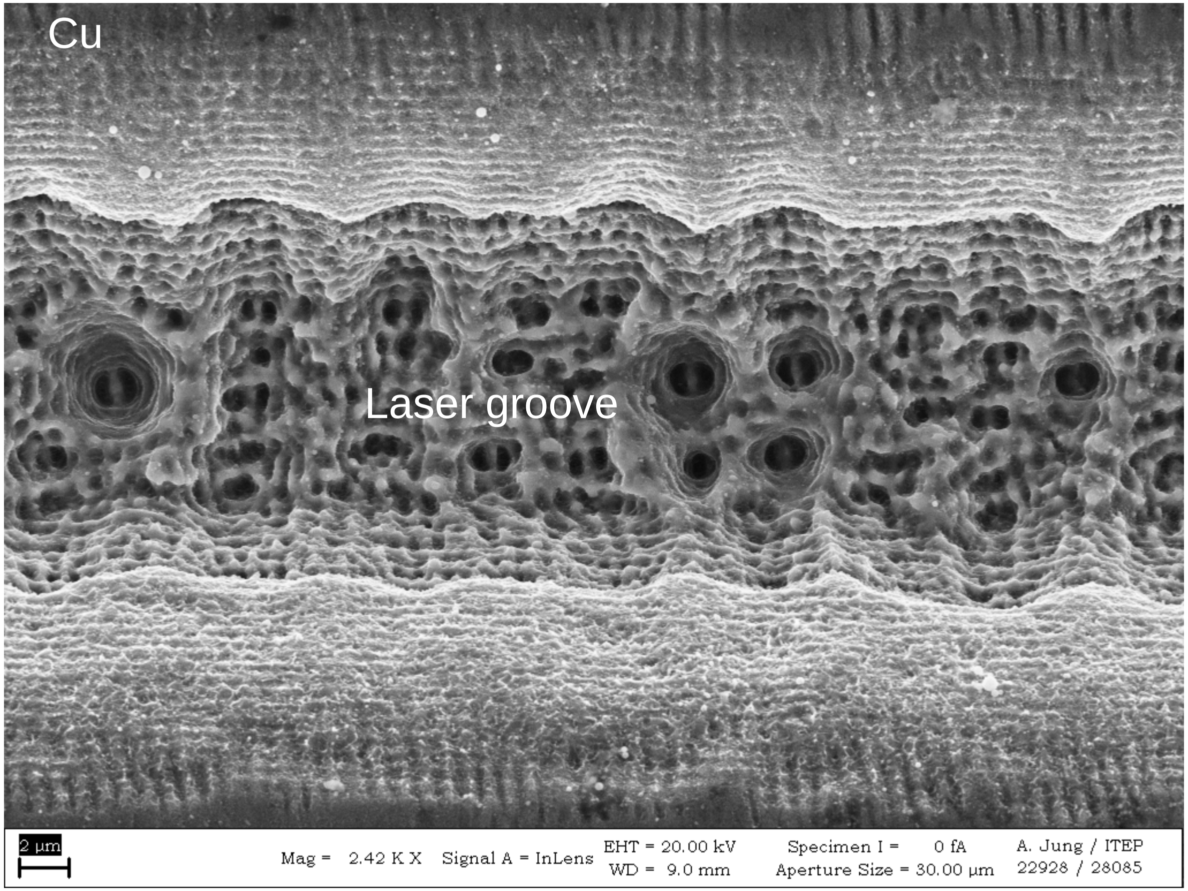


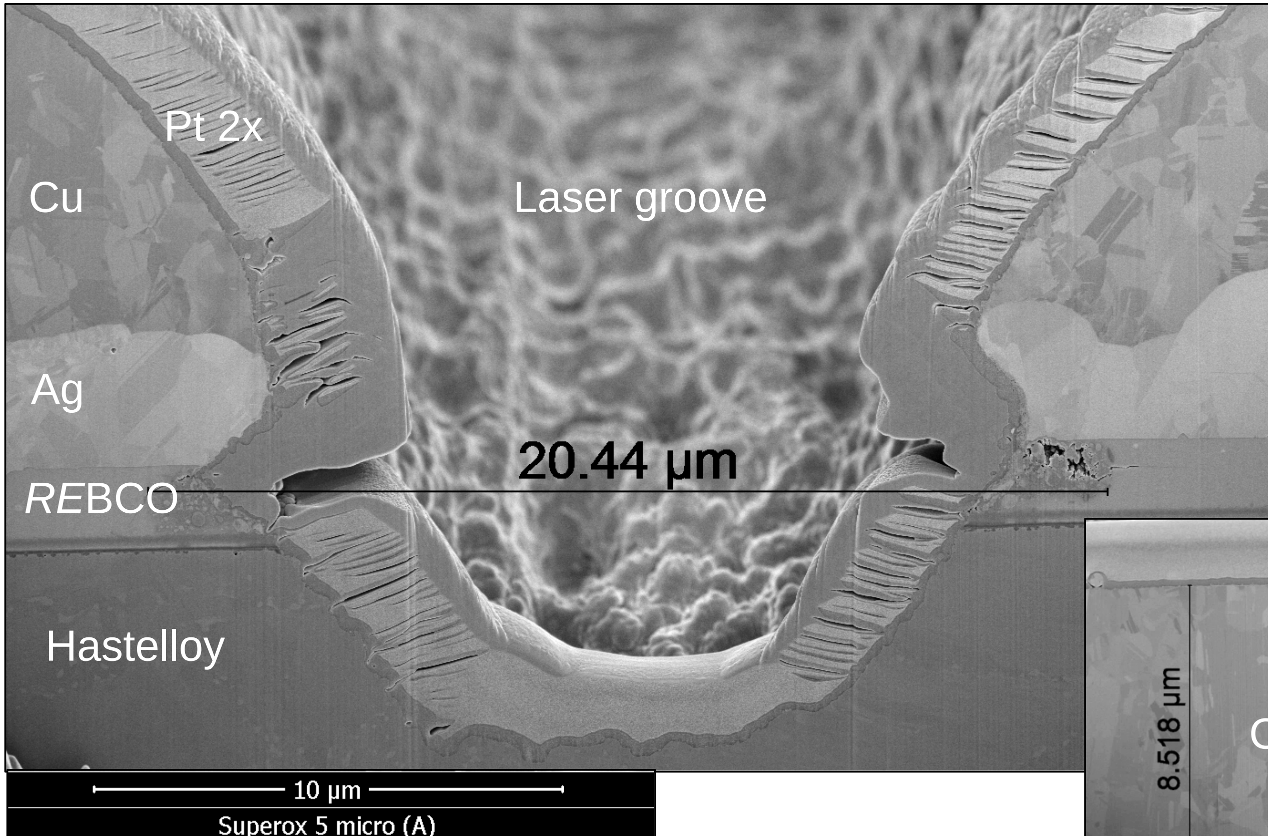
Top view of the groove in tape with 5 µm Cu stabilisation:

Karlsruhe Institute of Technology

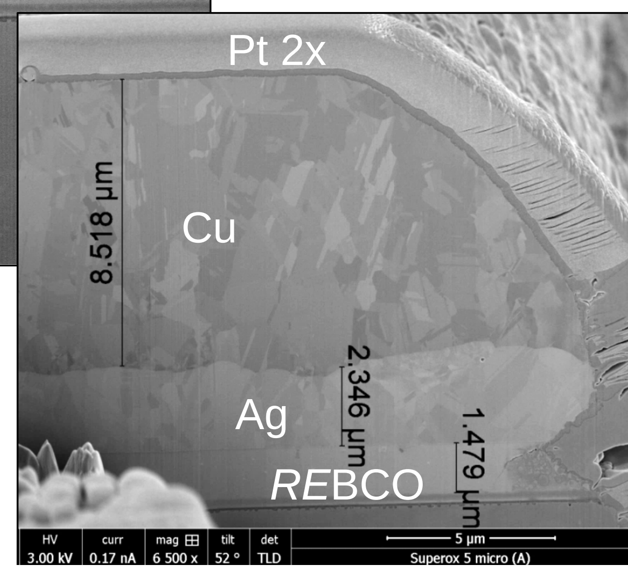


- SEM and EDX of the groove top view

Homogeneous cross-section of the tape with 5 µm Cu layer:

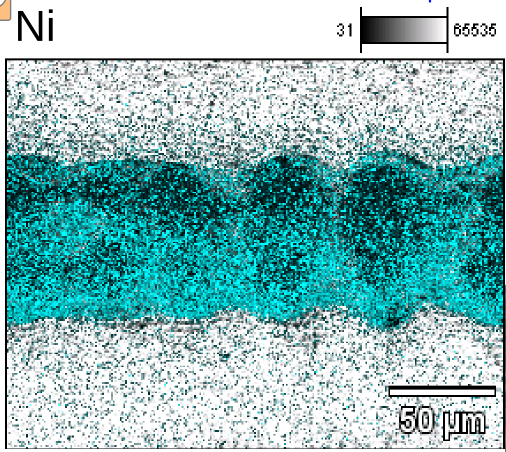


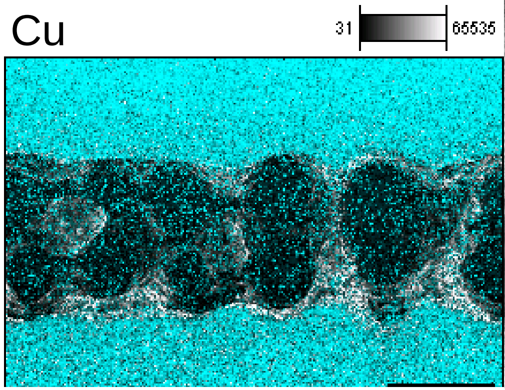
- *RE*BCO 1.5 µm
- Groove width 20 µm

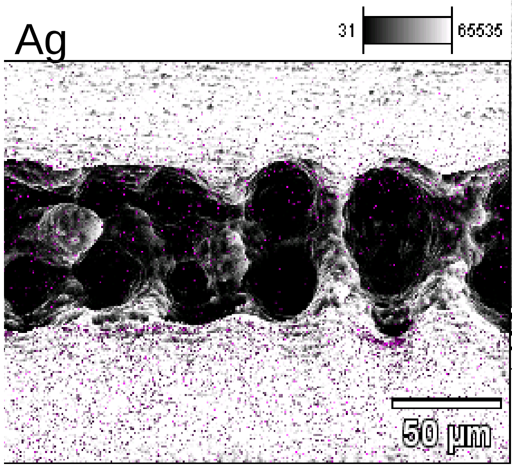


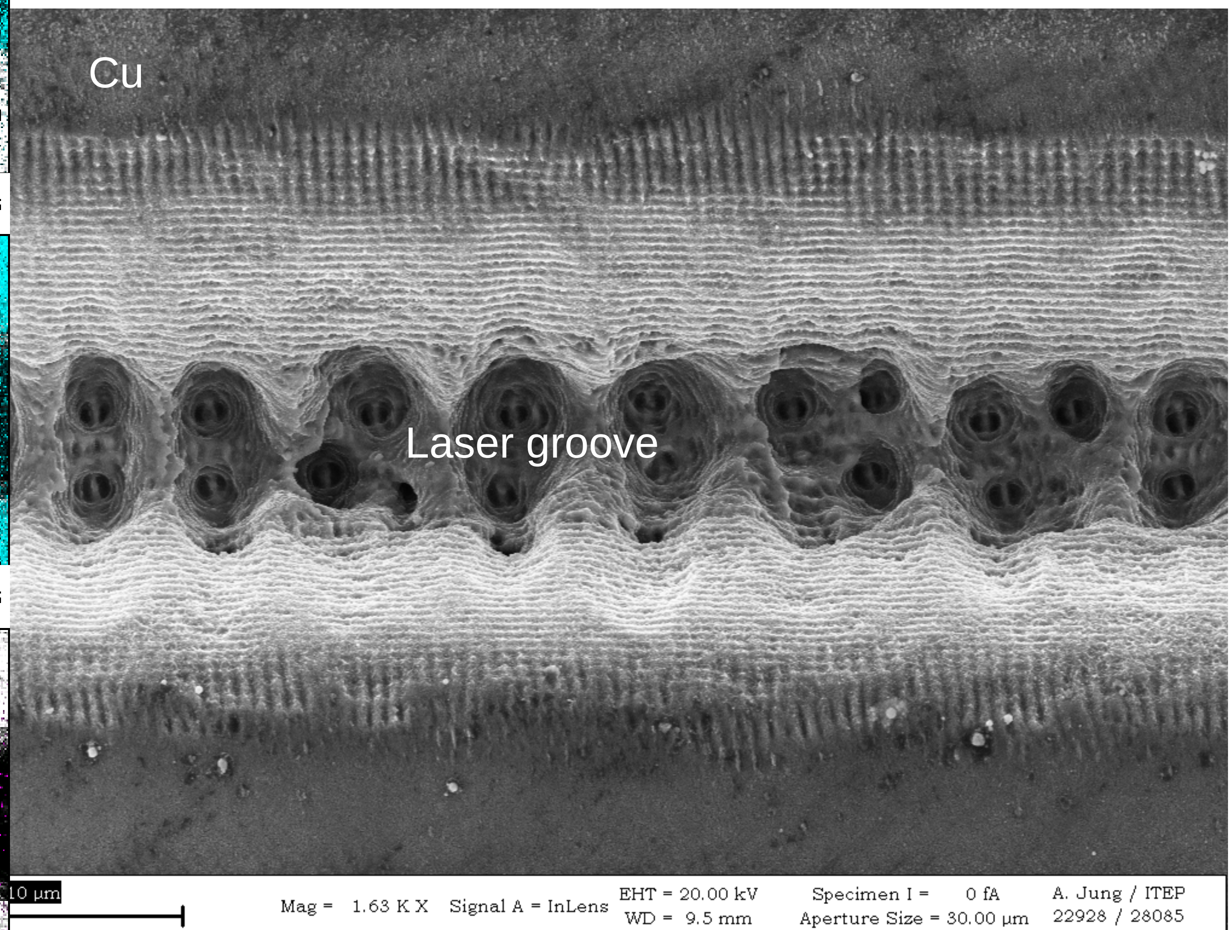
- Focus Ion Beam cut perpendicular to the laser groove.

Top view of the groove in tape with 10 µm Cu stabilisation:



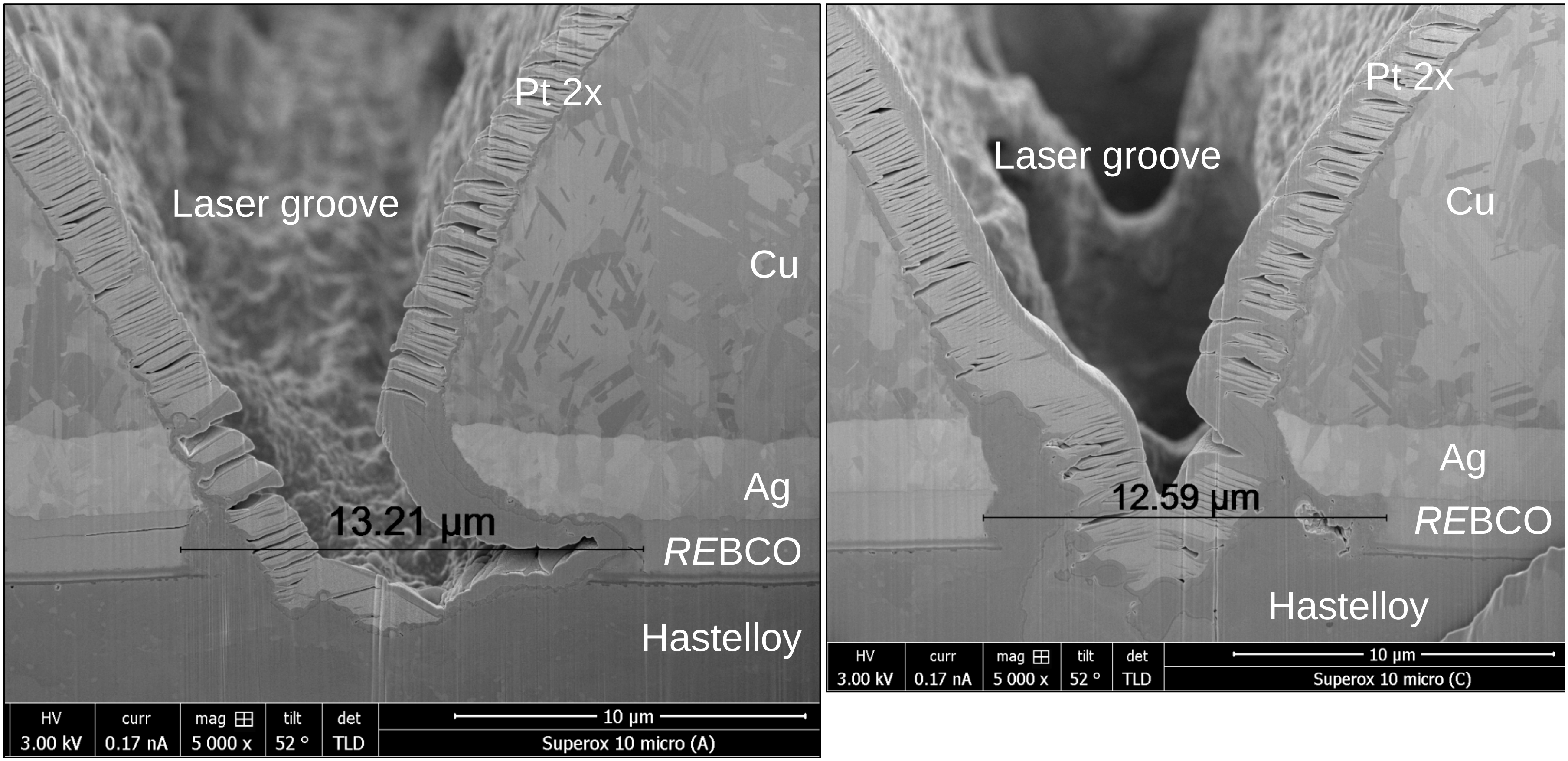






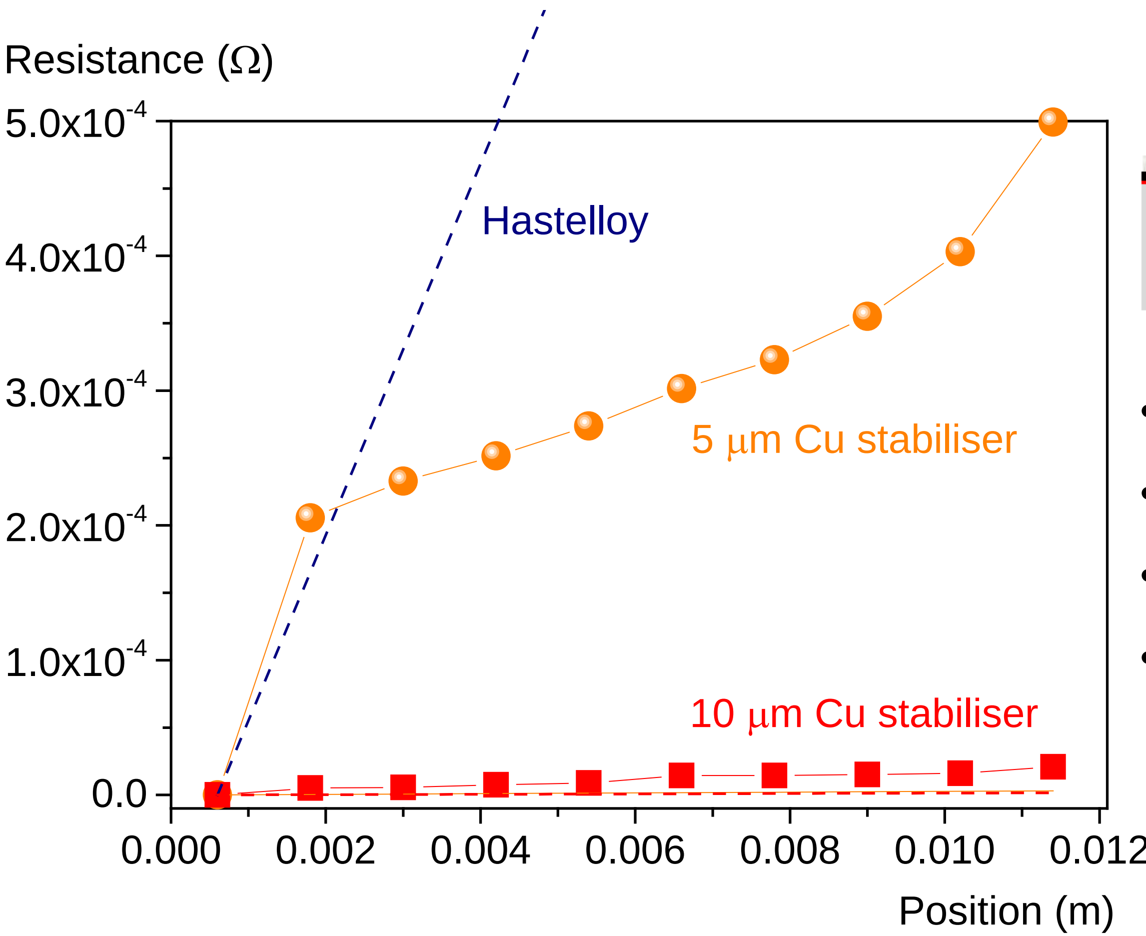
- SEM and EDX of the groove top view

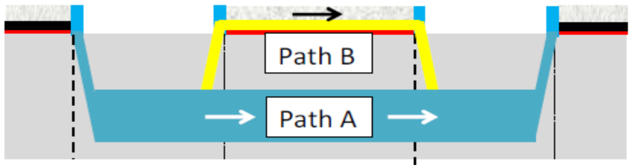
Relatively homogeneous cross-section of the tape with 10 µm Cu layer:



- Focus Ion Beam cut perpendicular to the laser groove
- *RE*BCO 1.5 µm, groove width 20 µm

Two possible current paths across the tape:

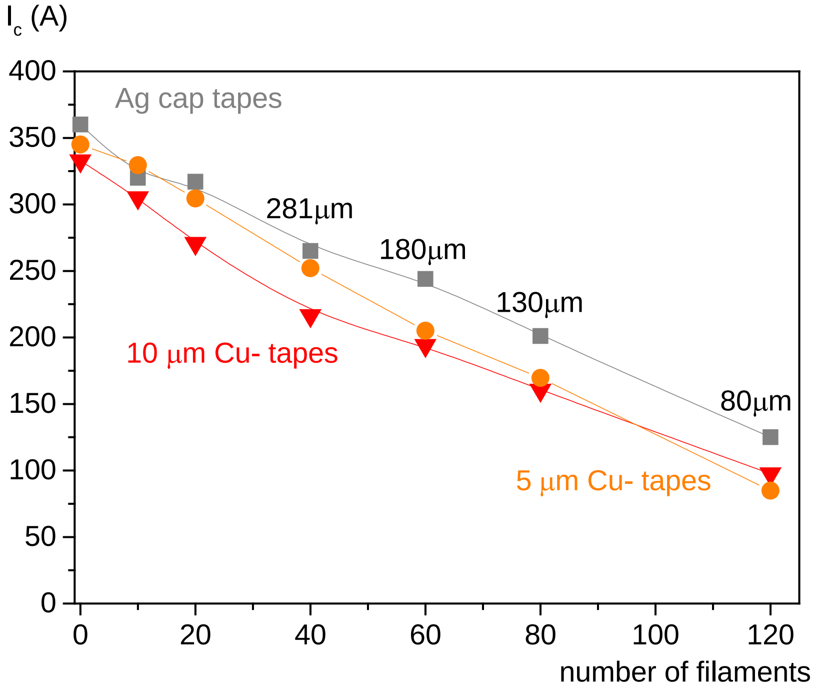


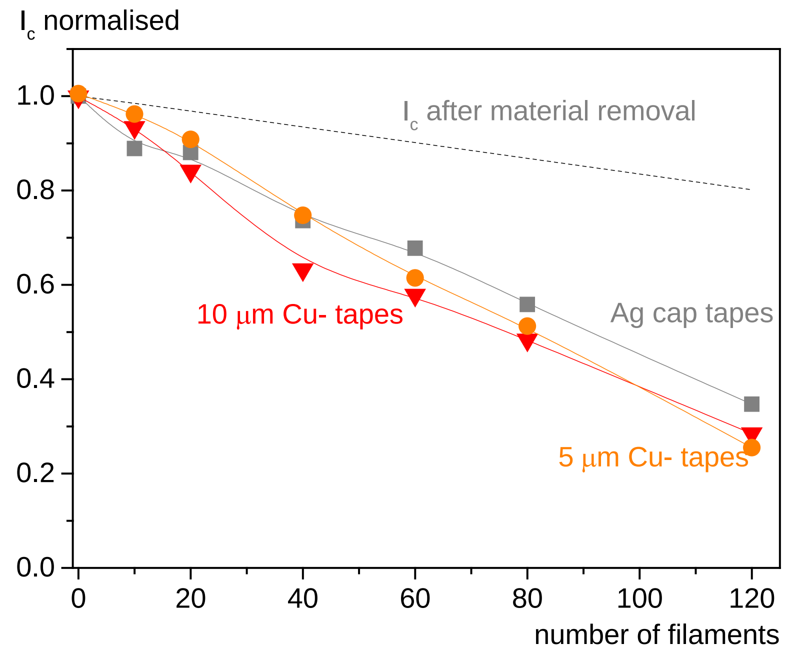


- LN_2
- Transport measurements
- Resistance across the tape
- Possible ways for coupling currents

- 5 µm Cu: 80% path A, 20% path B
- 10 µm Cu: 2% path A, 98% path B

I_c redaction caused not only by material removal:





- Strong (80%) I_c degradation with 120 filaments.
- Similar current reduction at tapes with 5 and 10 µm copper stabilisation.
- Stronger current redaction in Ag-cap samples than only coming from removed material.

Laser filaments of the different tapes:

Karlsruhe Institute of Technology

SuperOx

Laser cutting

5 µm Cu — 5 Watt / 50 passes

10 µm Cu — 5 Watt / 60 passes

- 0-120 Filaments
- 12 mm width

Ag — Laser cutting 5 Watt / 10 passes

- Oxidation (500°C / 1h)
- Cu plating

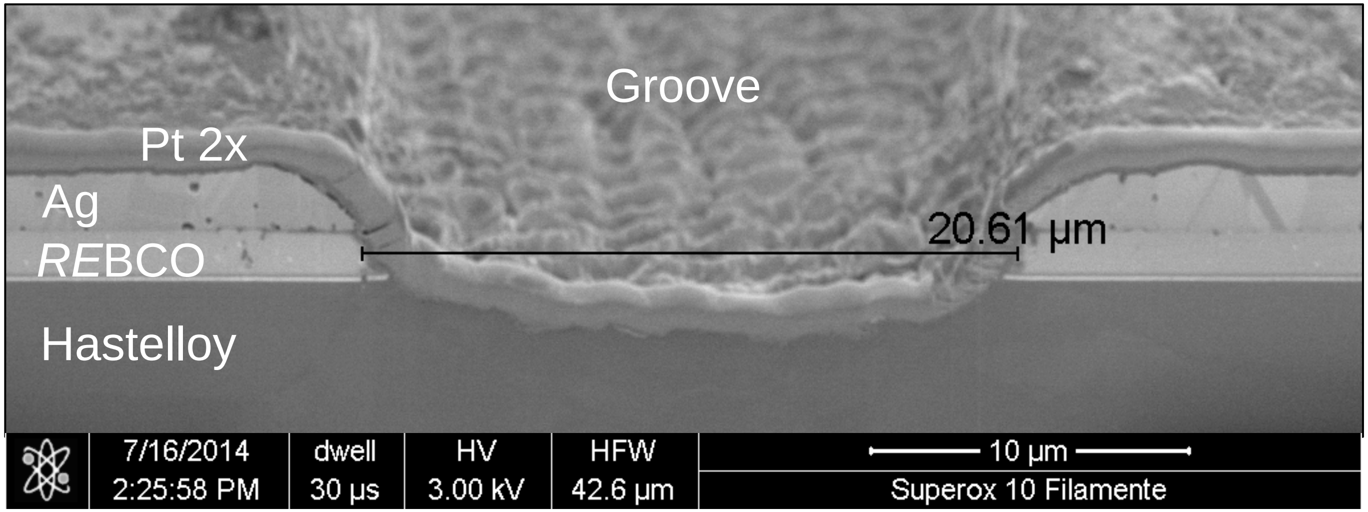
5 µm Cu

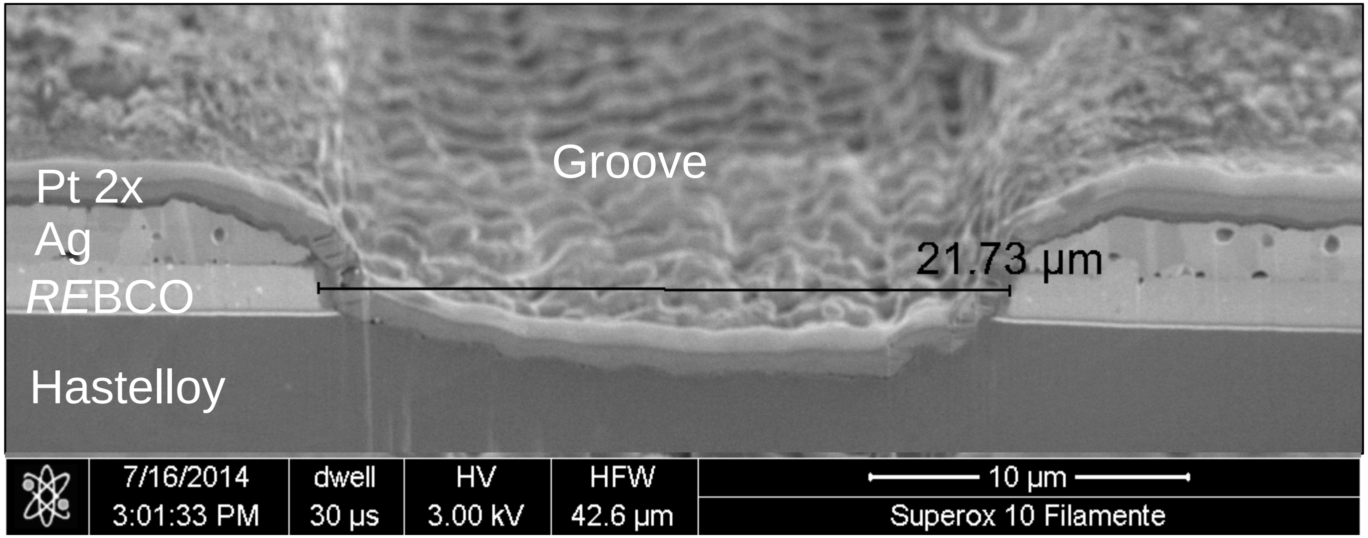
7 µm Cu

10 µm Cu

- 0- 60 Filaments
- 12 mm width

Homogeneous cross-section of the tape with Ag cap:





- Ag cap
- *RE*BCO 1.5 µm
- Groove width 21µm

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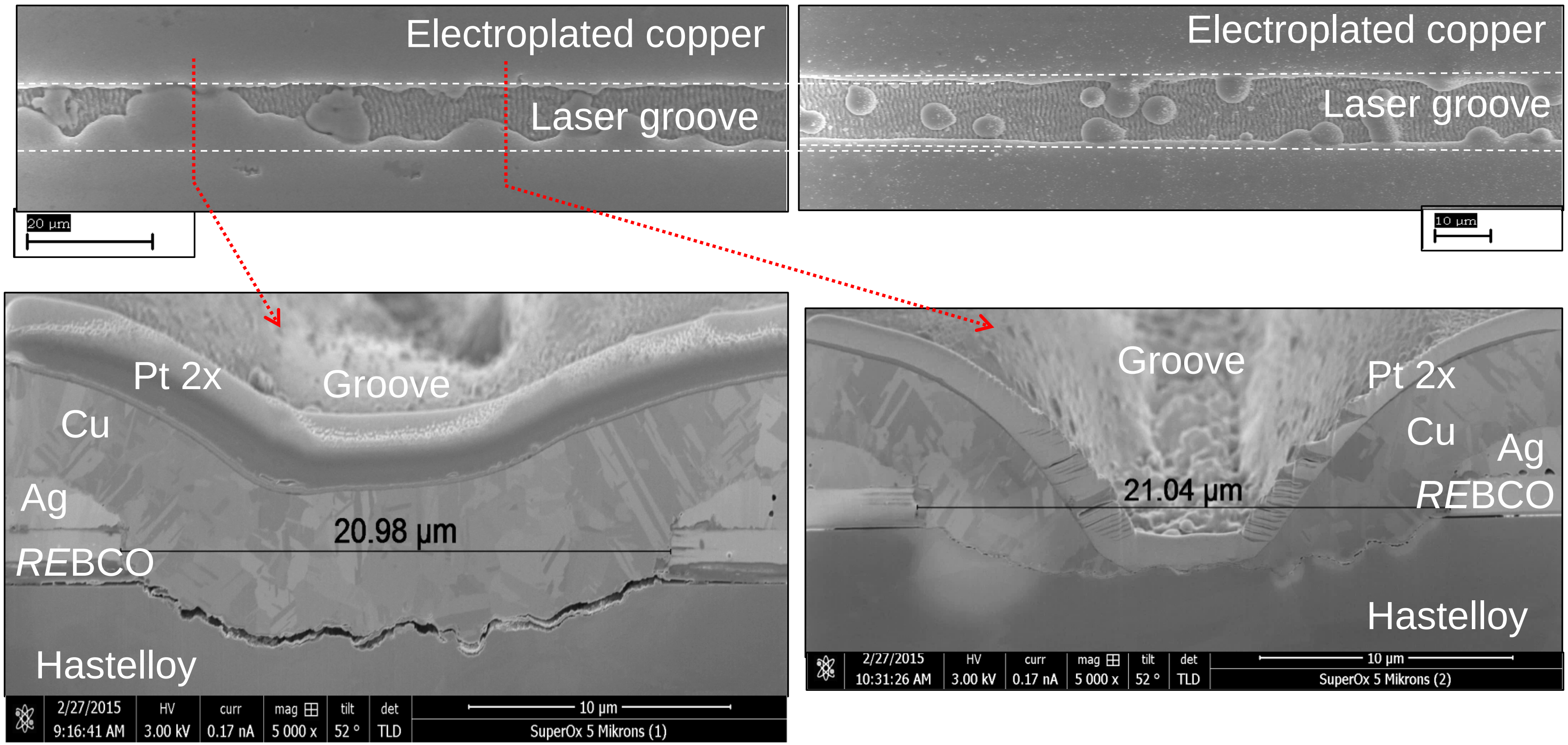
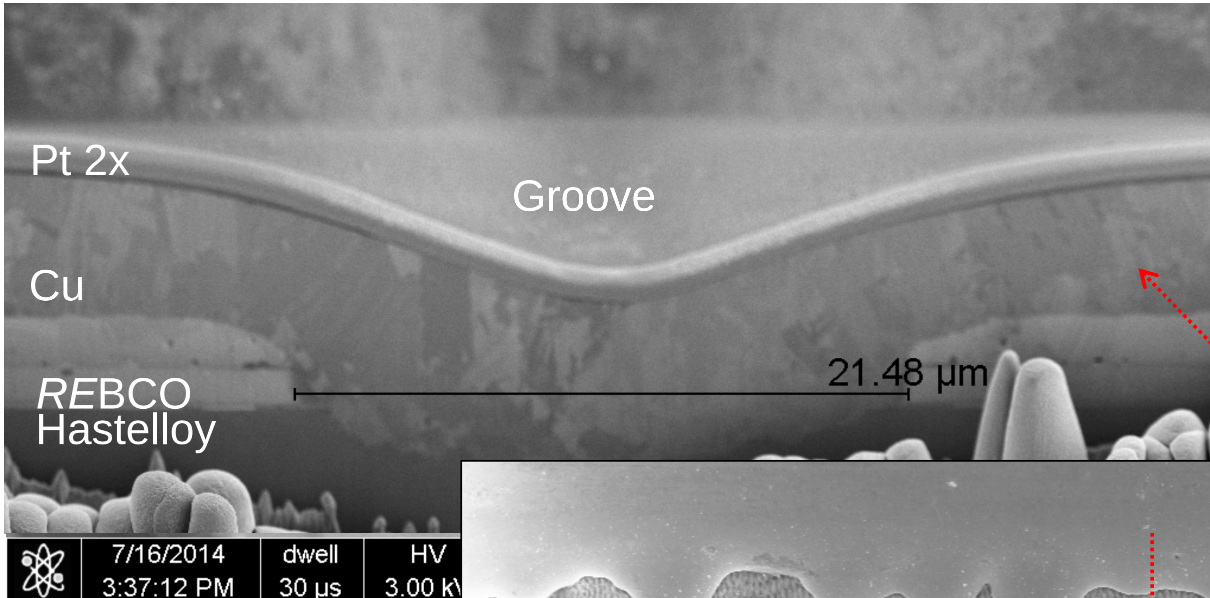
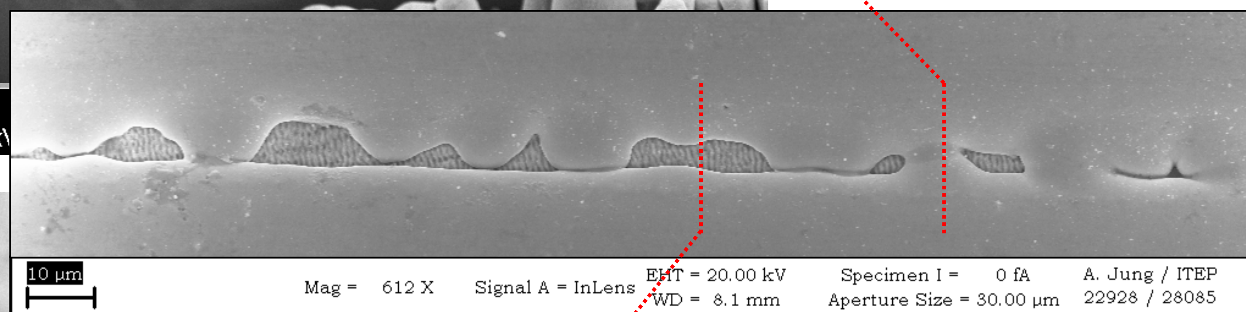
Copper - 5 µm - partially deposited on the oxidised groove:

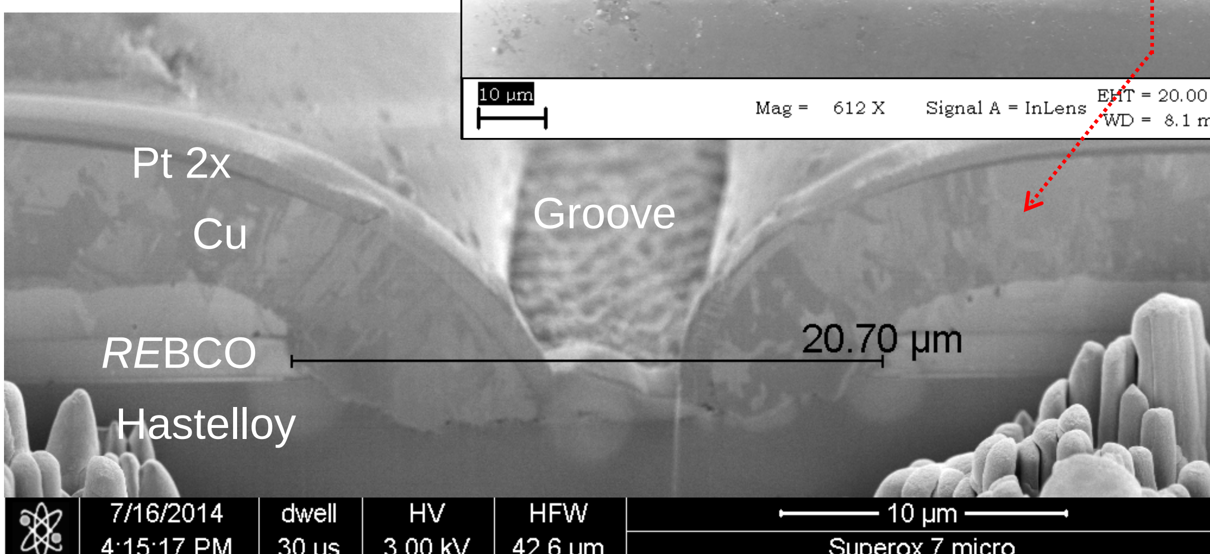


- Inhomogeneous deposition copper into a grooves
- Copper bridges across laser groove

Copper - 7 µm - half deposited on the oxidised groove:

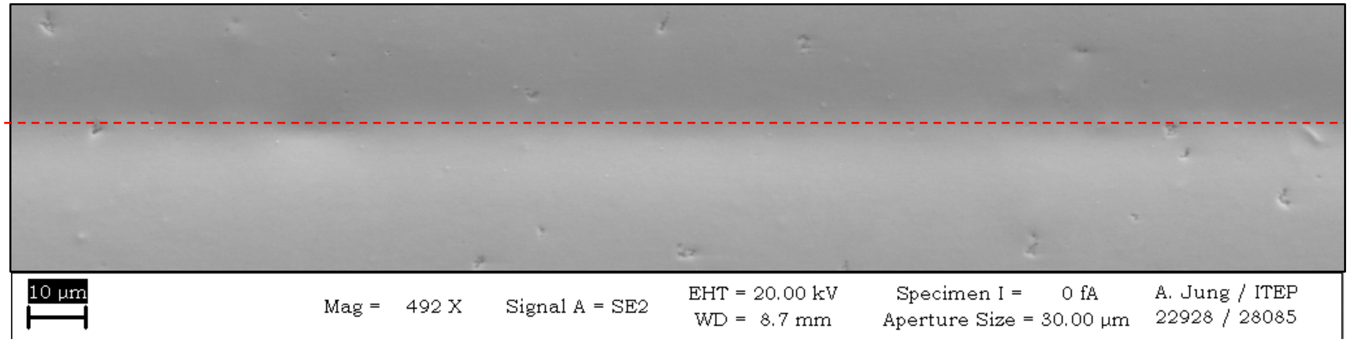




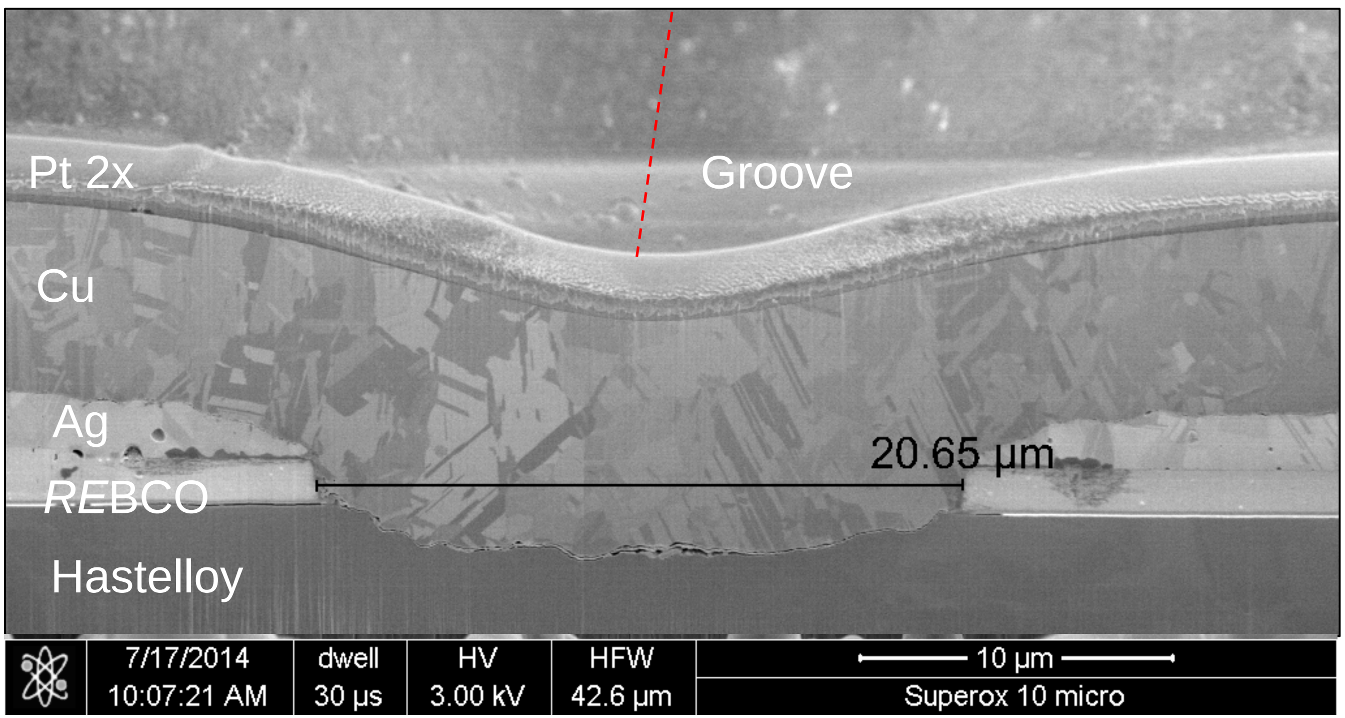


- Deposition does not depend from number of grooves (sc filament width).

Copper - 10 µm - deposited along entire oxidised groove:

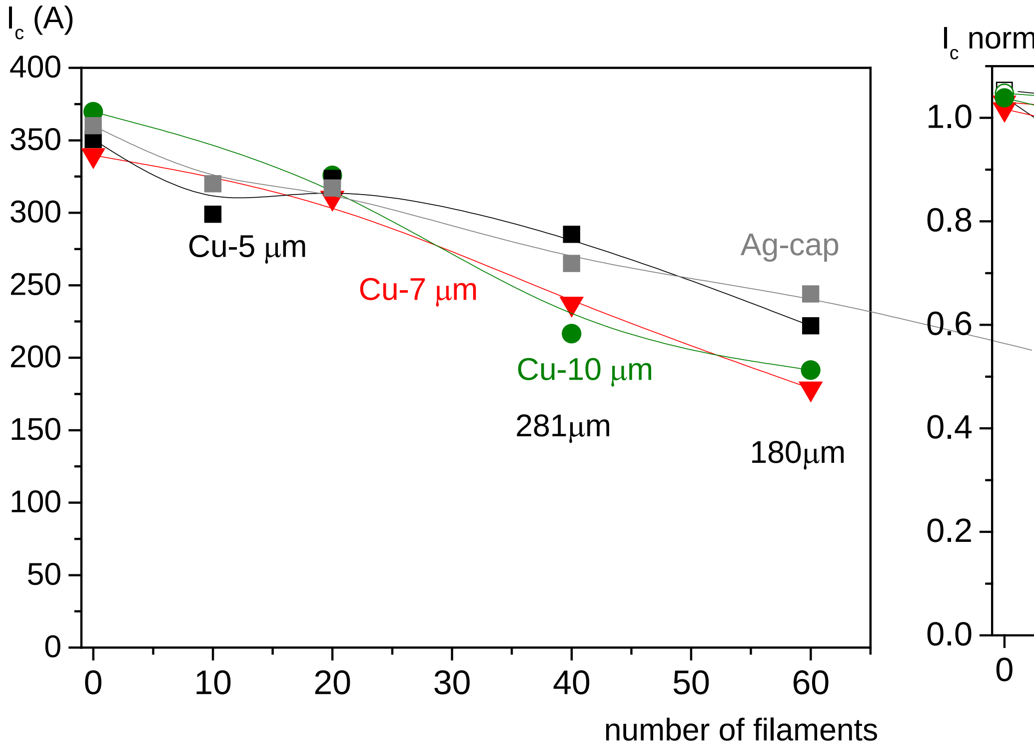


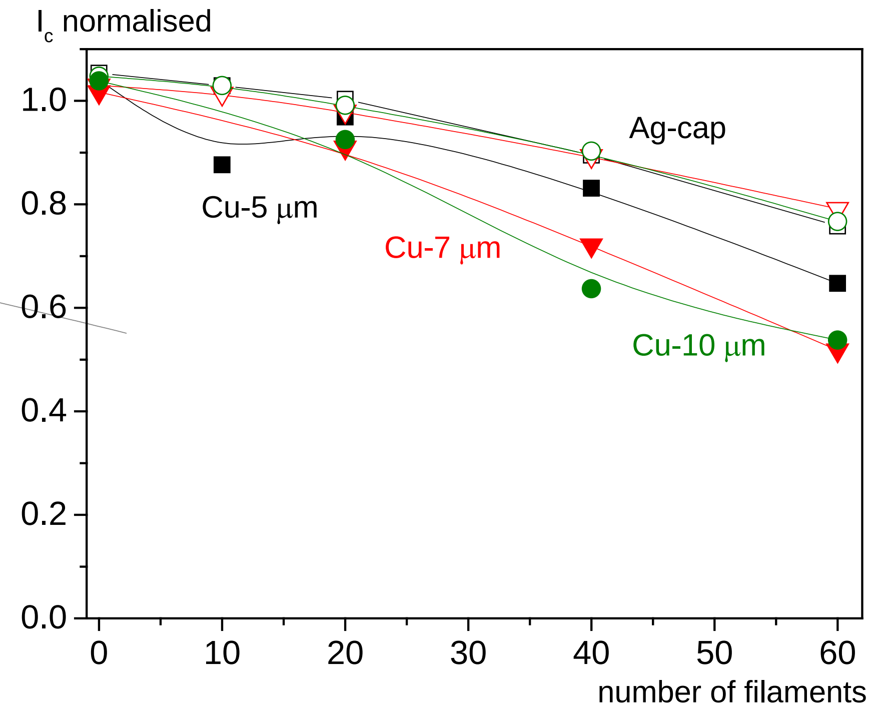
- Groove top view.



- Deposition do not depend from groove number. (sc filament width)

Critical current reduction due to used electrolyte:

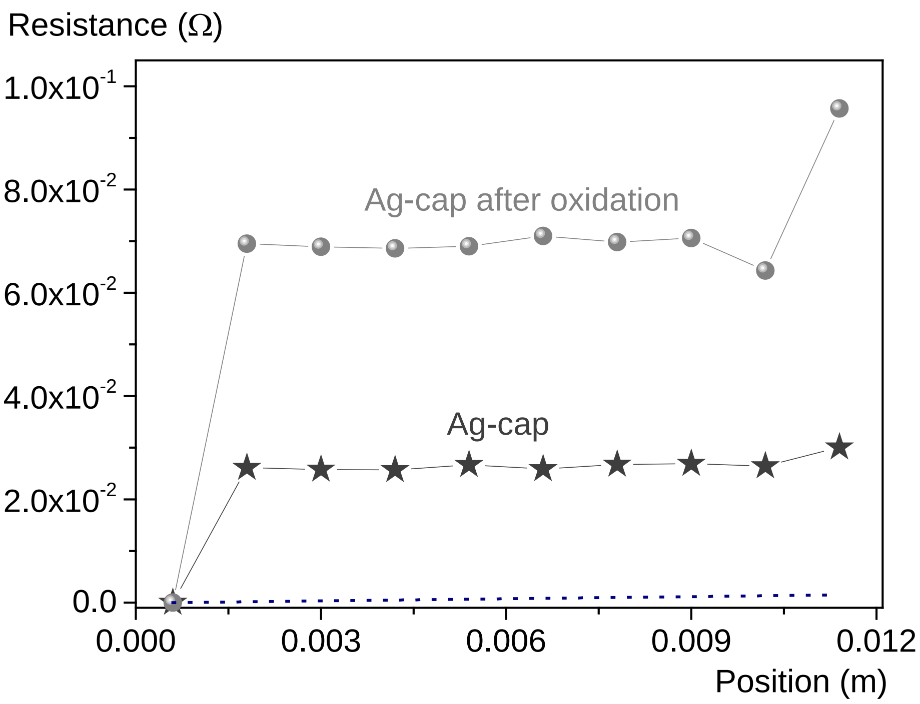


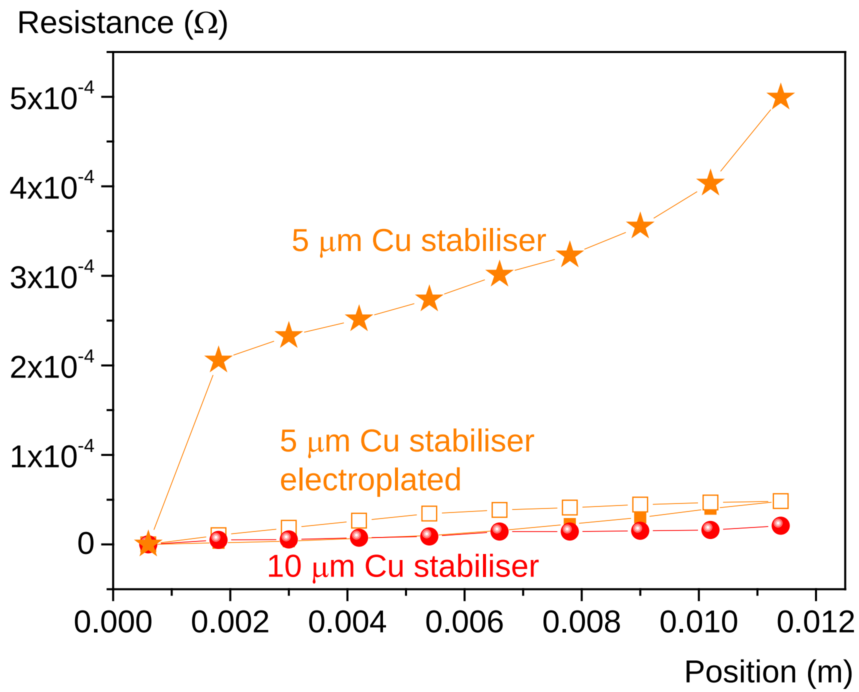


- Ag-cap tape non-oxidised
- Negligible reduction in I_c with 5 µm Cu

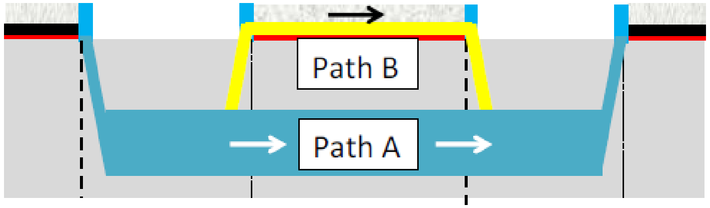
- Small I_c reduction due to electrolyte
- Smaller reduction with 5 µm Cu
- Stronger reduction with 7 and 10 µm Cu

Current flow across Cu bridges in electroplated samples:

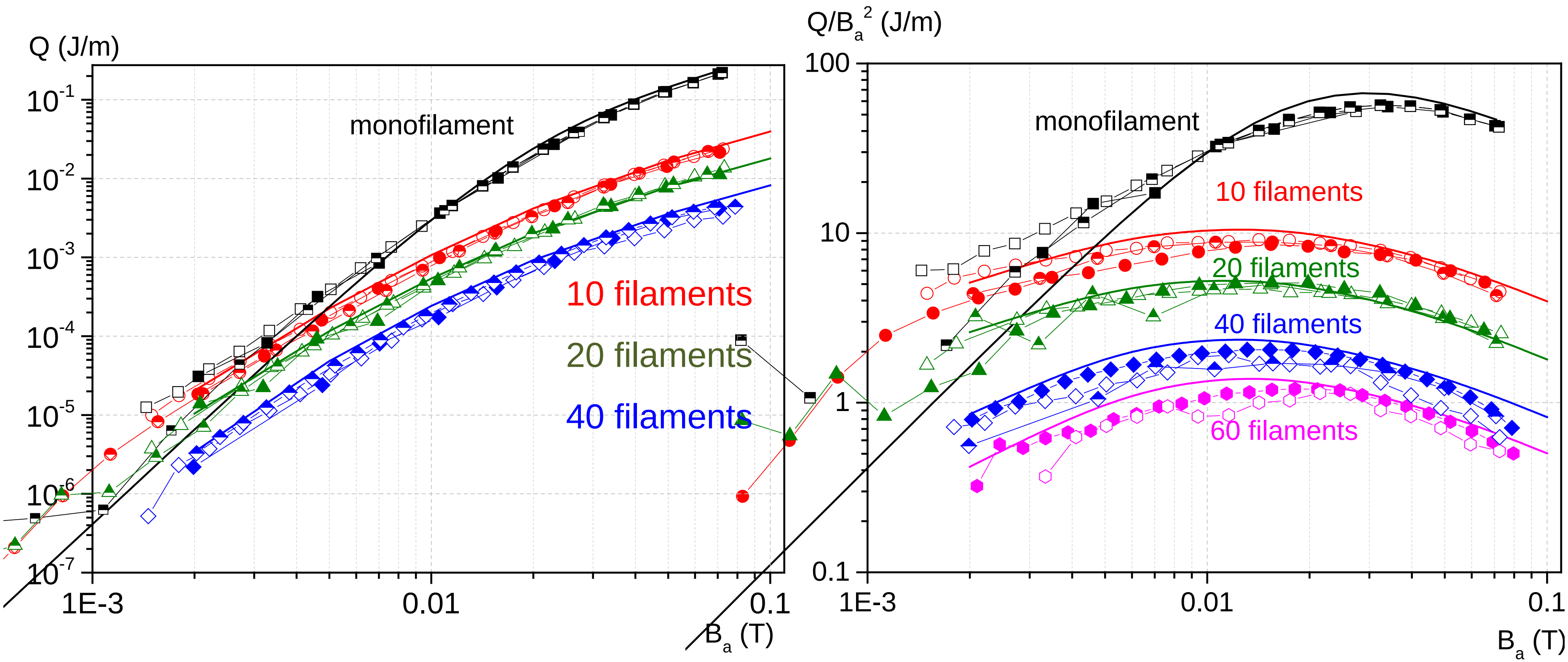




- Oxidation enhance resistance (Ag – cap)
- Electroplated samples: current path B
- Ag-cap samples: current path A

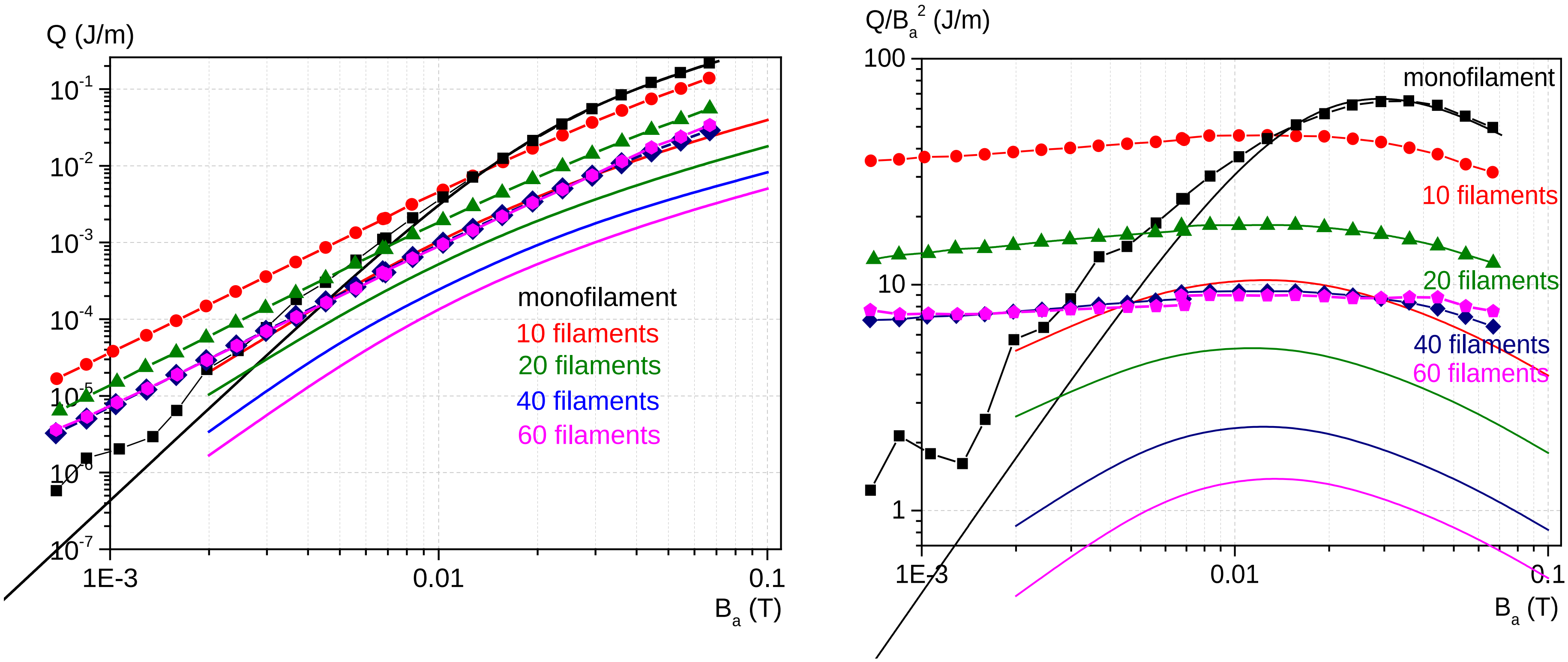


No coupling losses at oxidised Ag cap tapes:



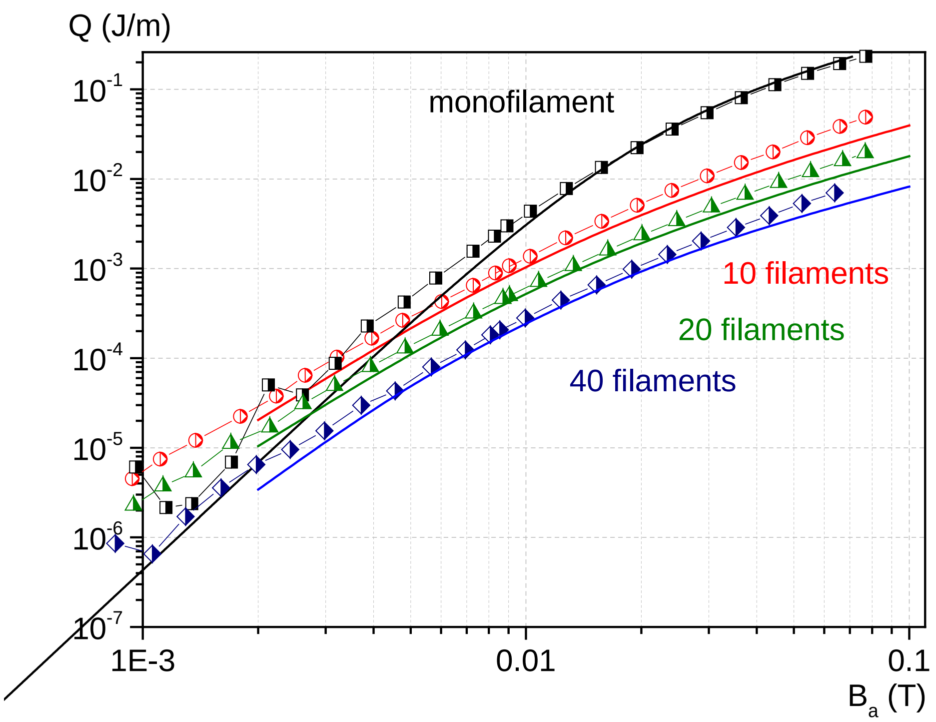
- LN_2, calibration free method
- Fully uncoupled limit - analytical formula from Mawatari PRB 1996 (lines)
- Different frequencies measured: 12, 72, 130 Hz

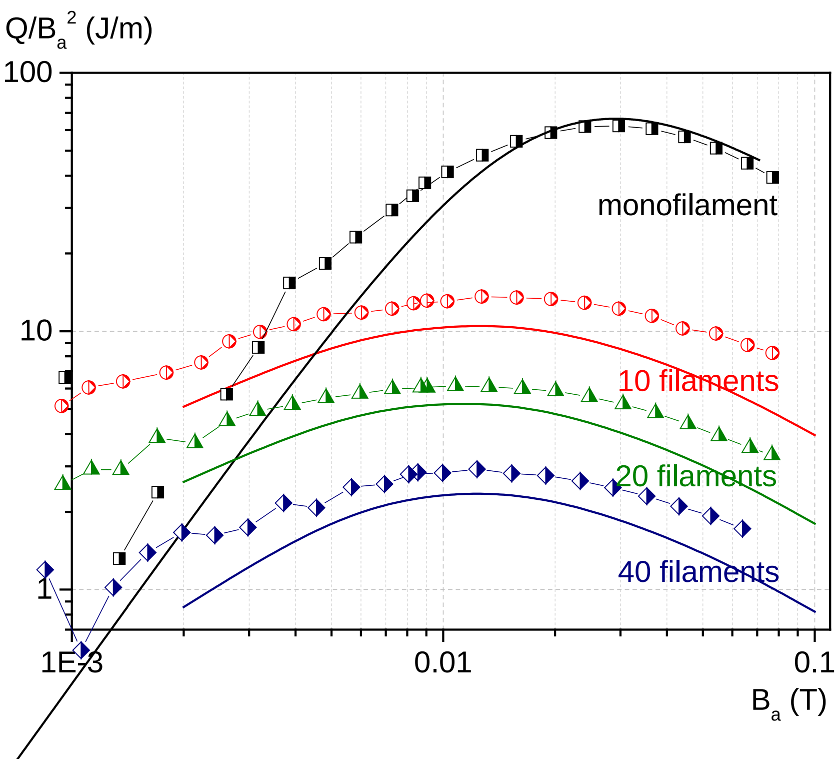
Coupling losses visible at Ag cap after 5 μm Cu electroplating:



- LN_2, calibration free method, frequency 72 Hz
- Fully uncoupled limit - analytical formula from Mawatari PRB 1996 (lines)
- Coupling losses higher than magnetisation losses

Magnetisation loss reduction at low frequencies:





- LN_2, calibration free method, Frequency 6 Hz
- Fully uncoupled limit - analytical formula from Mawatari PRB 1996 (lines)
- Coupling losses negligible, reduction of the magnetisation loss

Summary:

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- Two different methods were applied:

  top down: laser cutting through Cu+Ag+*RE*BCO.

  bottom up: laser cutting through Ag+*RE*BCO and electroplating.

- Both methods depend strongly on material homogeneity.
- Laser cut narrow, well defined lines in the case of thin materials.
- Industrial copper plating process at SuperOx was used.
- Coupling loss due to resistive bridges on the laser groove observed.
- Low AC losses at low frequencies were obtained (close to theory expectations).
- Loss reduction by factor of 30 at 100 mT applied magnetic field with 40 filaments, when I_c reduced by 20% (6 Hz).