# Ink-plotting of $YBa_2Cu_3O_{7-x}$- filamented structures


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## Introduction

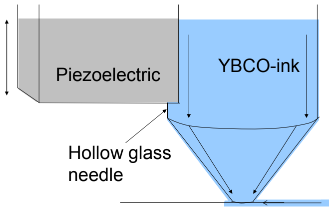
### Motivation

Chemical Solution Deposition (CSD) is a promising process for industrial long length production of high temperature superconducting tapes because of its low-cost, high-speed production and good scalability. $YBa_2Cu_3O_{7-x}$ (YBCO) coated conductors are the favourable material with excellent superconducting properties including sufficient high $J_c$-performance. Nevertheless, the alternating current (ac)-losses are still too high for applications of wires in motors. A special plotting technique allows a printing of filamented structures of YBCO thin layers. The hysteresis losses in such striped films are much lower than in continuously coated substrates with a homogeneous YBCO layer.

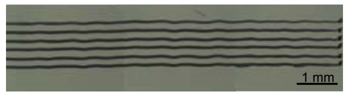
Lines as well as rectangular shaped YBCO-structures were deposited by an ink plotting system on single crystal substrates. Different inks were tested, among them an environmentally friendly, water-based fluorine-free YBCO precursor solution as well as an ink, synthesised according to the TFA route.

### Ink plotter „Sonoplot GIX Microplotter"

The ink plotter is capable of applying picoliters of fluid to a surface in order to create features up to 200 µm wide and more than 20 cm long. The core of the ink plotter is a dispenser, which is composed of a hollow tapered glass needle attached to a piezoelectric element. When an alternating current is supplied to the piezoelectric, it vibrates. At the resonant frequency of the dispenser the fluid is sprayed out at the end of the needle. Solutions with a viscosity up to 450 mPas can be used for plotting.




*Schematic setup of the ink plotter*




*example of a YBCO-pattern, plotted on STO substrate*

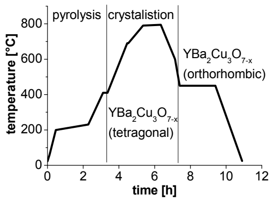
## Experiments

### Metal trifluoracetate precursors (TFA-route)

#### Solution preparation

A precursor solution was prepared of Ba-, Cu- and Y-acetates, propionic acid and trifluoro acetic acid. The sol-gel precursor was subsequently dissolved in a mixture of acetone / propionic acid with a ratio of 3 / 1. [1] The solution is characterised by a viscosity of 9.4 mPas and a molarity of 0.25 M.

#### Heat treatment (ex situ process)

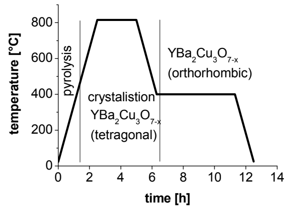



### Aqueous fluorine-free sol-gel process

#### Solution preparation

Ba-, Cu- and Y-acetates were dissolved in an acetic acid / water mixture with a ratio 1 / 4 to a total metal concentration of 0.8 M. The viscosity of the precursor solution is 7,8 mPas. [2]

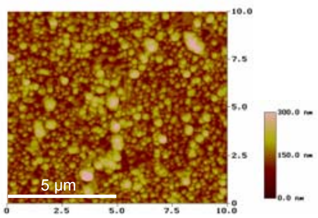
#### Heat treatment (ex situ process)



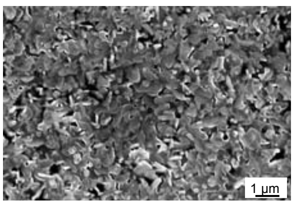

## Results

### Surface morphology and microstructure

The YBCO surface morphology of a ~ 120nm thick layer was measured by atomic force microscopy (AFM) and reveals a relatively high surface root-mean-square roughness (RMS) of ~ 47 nm. Scanning electron microscopic (SEM) analysis illustrates a porous but crack free YBCO layer with a small fraction of a-axis grains.



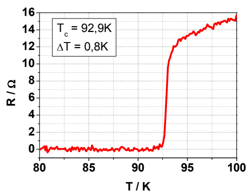

*AFM image of the YBCO surface after heat treatment*



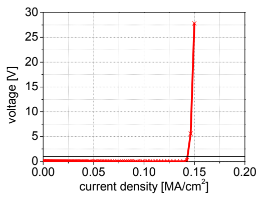

*SEM image of the YBCO surface*

### Superconducting properties

The transition into the superconducting state has been measured in a resistive PPMS (Physical Properties Measurement System) measurement. A high critical temperature ($T_c \approx 93$ K) with a sharp transition ($\Delta T \approx 1$ K) had been observed, which confirms a good degree of crystallization of the YBCO film. The critical current density $J_c$ was determined by PPMS measurements and shows a value of 0.14 MA/cm² at T = 77 K and B = 0 T.




*Resistive measurement of the superconducting transition temperature of the YBCO film*




*Resistive $J_c$ measurement (77 K, self-field) for the YBCO film*

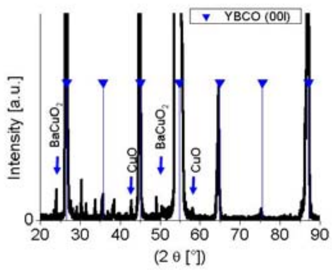
### Wetting properties

Coating processes, particularly of aqueous solutions, require a high wettability of the substrates. A special cleaning procedure described in [3] as well as an etching of the STO-substrate for 30 minutes in propionic acid can improve the wetting properties. Furthermore a small amount of surface-active agent (tenside) was added to the water based YBCO solution.

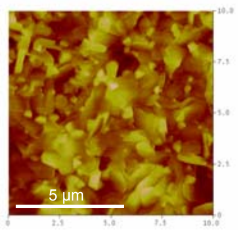
### Surface morphology and microstructure

A thin YBCO layer (2 mm x 8 mm, thickness: ~ 80 – 200 nm) was grown epitaxially on a $SrTiO_3$ substrate. The intensity of the different (00l) peak reflections shows a strong c-axis orientation of the YBCO grains. Beside the YBCO phase still some impurities can be observed. Furthermore, the surface active agent leads to the formation of bubbles, which can be observed even in the light microscope.

From the AFM image it can be clearly seen that the layer has a very porous surface morphology. This is related to the vigorous auto combustion reaction of the organic components.




*X-ray diffraction 2θ-scan of the YBCO layer plotted on a STO substrate*




*AFM image of the surface YBCO-layer after heat treatment*

## Conclusions

The "Sonoplot Microplotter" is an appropriate device for plotting structured patterns of YBCO layers. YBCO layers prepared from TFA route obtained a $T_c$ of 93 K, $\Delta T \approx 1$ K and a $J_c$ of 0.14 MA/cm² . Further optimisation of the process is required.

A non-fluorine water-based sol-gel precursor was also used for plotting of YBCO layers. In this case the wetting properties of the substrate are crucial. XRD measurements confirmed the formation of an epitaxially grown YBCO film.

## References


[1] Gupta A., Jagannathan R. et al., Appl. Phys. Lett. 52 (1988), 2077-2079
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