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## Coated Conductor Processing: Copper Stabilizer

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### Abstract

We present here a report about a copper stabilizer processing unit and the function on IBAD – HPLD coated conductor properties. A continuous reel - to- reel Cu plating stabilizer manufacturing technology was developed and will be transferred to Bruker HTS. The quality and performance of one- side and double- side 20  $\mu\text{m}$  Cu layers are evaluated with respect to critical current behavior and conductor joint fabrication. By current pulse plating technology in copper sulphate  $\text{CuSO}_4$  we have gained to optimize the plating speed to more than 30 m/h by variation the electrical, electrode and solution parameters. With the new 6 m long Cu reel plating unit improved production yield and reproducible Cu stabilizer performance is demonstrated. The non-vacuum deposition unit has a high flexibility in processing a homogeneous Cu stabilizer of thickness of 5 – 50  $\mu\text{m}$ . Using the Cu layer face -to -face joints with resistances of  $10^{-7} \Omega\text{cm}^2$  level by standard soldering are becoming routine. We will provide an overall analysis of our construction and results in the PLD Cu – HTS hybrid conductor engineering and processing.

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*Keywords:* Coated conductor; copper plating; reel-to-reel; conductor joining;

### 1. Introduction

Mid century energy power requirements, that from their generation are free of carbon dioxide emission, could be several times more what we now produce. Besides of possible candidates of primary energy sources like solar and wind energy, biomass, nuclear power, and still fossil fuels non- primary power technologies like hydrogen, transport, storage, and superconducting systems could contribute to energy and climate stabilization. Even all of these approaches currently have severe deficiencies that limit their

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ability in solving the total energy challenges each technology has to be evaluated and scaled –up to investigate technological options. High-Tc superconductors can contribute to energy efficiency; reduce the volume, weight, dissipation and losses in electric machines, motors and generators. A basic condition is the quality and availability of HTS conductor material, especially the second generation wire. ATZ and Bruker HTS cooperate in the field of PLD conductor development and aiming a long- length conductor manufacturing. Thereby, the 2G HTS wire is fabricated in basic continuous automation processes of surface polishing, IBAD - YSZ, high rate PLD, Ag thin film sputtering and copper plating. In each process the deposition rate determines the final production efficiency.

Electroplating of a copper stabilizer with thicknesses between 10 – 50 µm on the surface has been evaluated as improving the engineering performance of the conductor substantially. First plating process using single galvanic cell and copper sulfate solution are performed more than one decade before by us [1, 2]. A number of patents covering copper plating have been filed and are issued [3]. A smaller process unit was developed 4 years ago with single plating chamber for conductor length up to 200 m.

## 2. Copper sulfate pulse plating process

The major advantage of copper electroplating in aqueous CuSO<sub>4</sub> solutions is the non-vacuum method and the economy. Secondly, the element copper possesses a unique physical and chemical position in all new HTS materials. Because of the physical and chemical affinity of copper layers, we observed strong bonding between the metal on the surface and the HTS. Thirdly, the electroplating method could be easily transferrable into a continuous automat deposition process deposit at rates which are comparable with the other CC manufacturing steps (> 40 m/h).

The CuSO<sub>4</sub> plating process is most effective and non-poisonous for copper plating in contrast to the Cu(CN) route. For an effective working plating unit the electrolytic solution is moved in a circular process in permanence or periodically to remove impurities and to prevent sticking of reaction products on the HTS surface. The current source is manufactured and assembled for low HTS cathode conductivity (Hastelloy) and allows the current flow constant, reverse or in a wide ratio of pulse plating. The period and time window between positive current, zero and negative current is variable in a range up to 1 kHz (1ms) pulse current. Due to pulse plating the applied chemical current density in the solution enables substantially higher values equivalent faster deposition rate. The layers become fine grained and are mechanically stable on the surface.

Experiments using magnetic fields close to anode or close to cathode were performed. The resulting Lorentz force is

$$F = Cu^{2+} / Me^{2+} (v \times B)$$

with  $v$  = velocity of the charged ions,  $B$  = magnetic flux density. The force component provides together with the flowing catalytic solution better conditions for a homogeneous and fine-grained layer structure. We also tested ultrasonic treatment during the plating but obtained less indications of improved speed rate or better layer properties. The principal plating process of copper from a CuSO<sub>4</sub> solution and the inherent

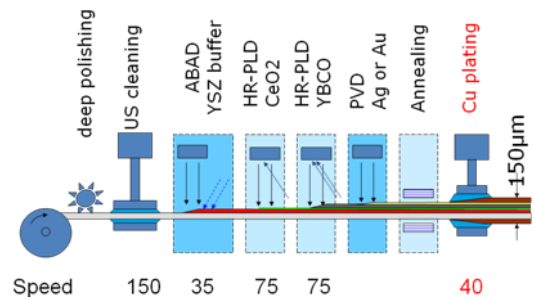
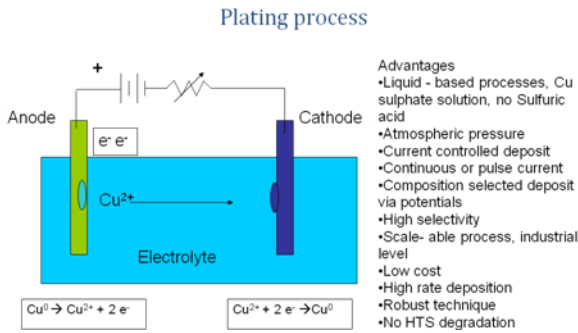
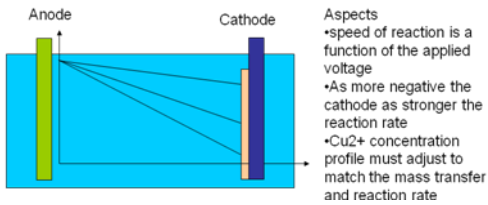


Fig. 1. Bruker HTS and ATZ 2G HTS wire manufacturing processes

electrochemical reactions are described in graphics of figure 2. The plating conditions and parameters follow the NERNST equations with chemical potential for  $\text{Cu}^{2+} / \text{Cu}$  (0.34 V). The  $\text{Cu}^{2+}$  concentration profile must adjust to match the mass transfer and reaction rate within the cell geometry.



**Cu deposition: Potential curves**



**Anode-Cathode Boundary layers**

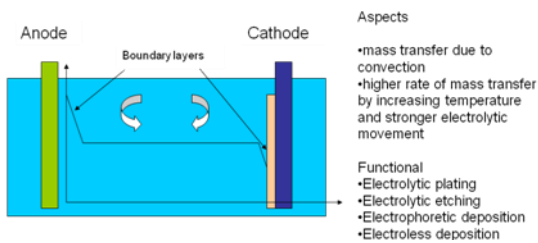


Fig. 2. Cu plating cell reactions

current will bypass the barrier through the shunt. Which part of the current is flowing into the shunt depends on the local ratio of the resistivities between the conductor matrix and shunt. Because at low temperatures as 77 K, the resistivity of copper is with  $0.2 \mu\Omega\text{cm}$  nominal the lowest of all metals and the electric stabilizer function is rather effective. In fact, the thin film Cu resistivity can be higher by a factor of 2-3 dependent thickness and purity. Nevertheless,

For effective plating over long times the aqueous electrolytic  $\text{CuSO}_4$  solution has to be circulated and cleaned. Especially the anode residual (mud) has to be removed periodically. In contrast to continuous plating with a given plating current the pulse plating technology possess two advantages: At a typical pulse period the positive pulse has duration of 10 ms with 30-40 ms dead time. The latter enables the surface relaxation before the next plating pulse. This procedure results in denser and fine grained layers. Macroscopically, pulse plating with alternating cell groups under current limits the total current load on the tape.

**3 Copper stabilizer function**

Originally, we developed Copper plating for contacting and joining bulk and thick film superconductors. Shortly later, a resistive fault current limiter (FCL) project was searching for a resistive shunt (CuNi, SS) as quench protector which should thermally and electrically be connected to the superconductor surface by a low resistivity. Within these activities design and plating of a copper stabilizer on thin film devices were coming into the focus.

As it is shown in figure 3 the Cu stabilizer and conductor matrix play an interfering role in bypassing the current and heat when a weak link or a hot spot appears in the wire. Figure 3 shows schematically the bypassing character and function of the copper layer. If the current flow is contacting a resistive barrier, part or all of the

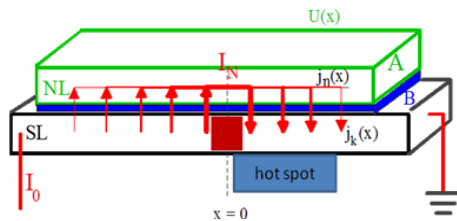


Fig. 3. Model of copper stabilizer for by-passing the super current

the copper shunt prevents a quench of the conductor part which is in normal use unwanted (in contrast to resistive FCL). As long as the current flow is without distortion the Cu shunt has no influence on conductor. In case of AC operation one observes however small AC losses increase due to the hysteric behavior of the metallic layer.

#### 4. Continuous reel-to-reel copper plating

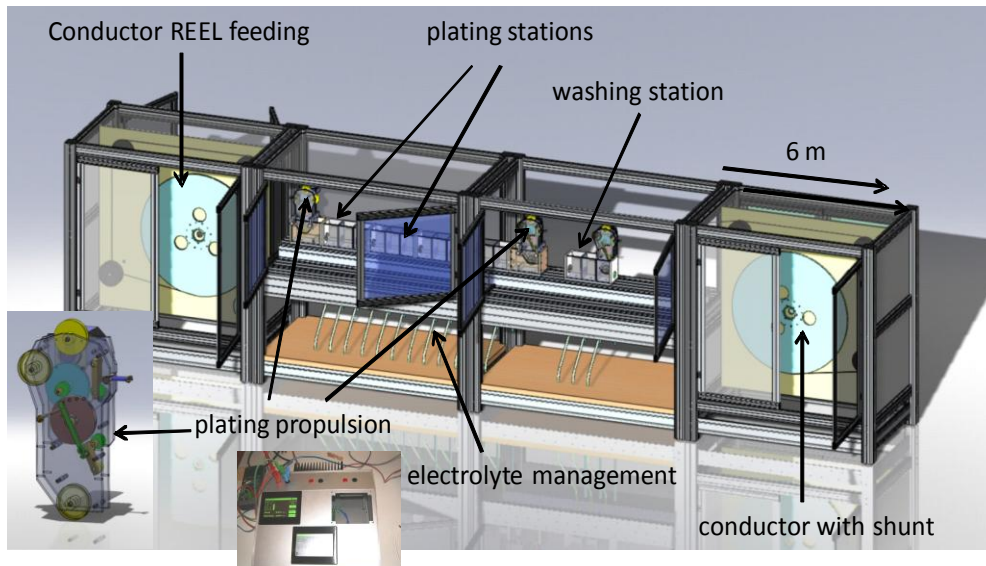


Fig. 4. Modular reel-to-reel copper plating unit with 12 station and long length tape transport (max. 2 km)

The progress in copper plating technique enables a pre- industrial and economical way processing in a reel-to reel procedure fully supporting the manufacturing needs for long length conductors. The new equipment fits into the BRUKER HTS remaining technology and is a constructive key in the manufacturing process for technical wires. The design of the reel-to-reel plating is given in figure 4. On both 33 inch reels are driven by stepper motors of variable speed and electronic control for the transport of up to 2000 m tape. In the center of the unit the tape is passing through 12 plating stations each powered by the plating cell current between the individual copper anodes and the tape as common cathode. The reel-to-reel transport system reduces the handling and fits the plating process cycle time by virtue it's closed –loop constant speed and constant tape tension control. The primary elements shown in figure 4 are described in the following.

The Cu plating stations are positioned in the centre consisting of 12 individual plating cells. The conductor is run through Teflon slits into the cells driven by two plating propulsion stepping motor units (insert of Fig. 4). The inner two units determine the speed of the tape through the cells and simultaneously feed the plating current into the conductor. The speed of the continuous plating can be varied by almost two decades dependent on the thickness of the copper layer. Typical tape speeds vary between 5 and 50 m/h. In Fig. 4, below the parallel switched plating cells the electrolyte is pumped continuously from separate 10 litre storage container into the cells to maintain a circulation and the concentration of the electrolyte. On the right side of the cells after plating the tape passes a washing station to remove rest slats or impurities from the surface. Finally, the tape is dried by warm air or nitrogen. An online layer thickness measurement follows before the plated tape is spooled on the right side reel. The complete equipment is oriented at semiconductor processing machines which we studied carefully. The modular

character with the plating stations provides an ease of process modification and line expansion. The plating process control is performed using the individual voltage-electrolytic current parameters of each cell. The cell voltage is an extreme sensitive parameter of the ionic conductivity of the solution. It is a measure of the actual concentration of the plating solution.

The new plating unit is currently implemented with final electronics control devices detecting the actual tape length on the reel transportation. First tape processing will be in autumn 2011.

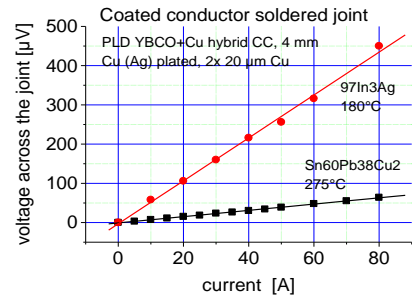


Fig. 5. I-V curves of practical soldered joints

## 5. Coated Conductor joint

Joining of the 2G conductors is one of the basic requirements for practical handling and operating. Except of the improved conductor properties the copper stabilizer enables a fast soldering and connection. Thereby it is important to solder the “face” side of the conductors, limit the solder temperature to about 270°C and minimize the solder layer thickness between the conductors. Our routine soldering tests give the best results with standard Sn60Pb38Cu2 solder material at a temperature up to 275°C. As displayed in figure 5 our soldering at substantial lower temperatures < 200°C using In3Ag solder was less successful. While with the above standard solder the joint has a low resistance of about 200 nΩcm<sup>2</sup> with In-solder at T=180°C the resistance was 10 times larger at the same overlap of 0.4 cm<sup>2</sup>.

## Summary

The design and construction of reel-to-reel copper galvanic deposition equipment for 4 mm 2G PLD conductor is here described. The processing unit consists of 12 modular plating stations. Micro-processor controlled pulse plating electronics limits the total plating current on the tape and enables deposition speeds from 5-50 m/h dependent on the layer thickness. The individual electrochemical reactions in a plating station were studied and optimized for rate efficiency and continuous processing. The reel transport system can operate up to 2000 m conductor length and fits into the basic PLD Bruker processing steps. Practical solder joining of currently lower-length conductors with standard SnPbCu solder gives overlapping resistance values of  $R = 0.2 \mu\Omega\text{cm}^2$  at 77 K.

## Acknowledgment

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