1. Introduction

Large-scale production of fully filamentized high temperature superconducting (HTS) coated conductors (CCs) [1] with high critical current \( I_c \) in the presence of an applied magnetic field [2] is one of the major technical challenges to be overcome in order to provide a wire with suitably low AC losses for applications involving hysteretic losses, such as motors, generators and transformers. Due to the high aspect ratio of the cross section of the HTS layer, the hysteretic losses in non-filamentized wire can reach unacceptable levels for many applications. Reduction of the high aspect ratio by thickness increase of the HTS layer is impractical from the manufacturing standpoint, as well as due to the well-known deterioration of critical current density \( j_c \) with thickness [3]. In order to reduce the high aspect ratio, dividing HTS tape into narrower filaments has been proposed [4], and experimentally demonstrated on a \( \text{YBa}_2\text{Cu}_3\text{O}_{7-x} \) (YBCO) film deposited on single-crystal \( \text{LaAlO}_3 \) [5], where the total hysteretic loss has been shown to decrease linearly with filament width, as predicted by hysteretic loss models [6–8]. A variety of top-down (striaion after YBCO deposition) techniques utilizing this approach, such as laser ablation [5,9], mechanical striation [10] and photolithography followed by dry [11,12], and wet [13] etching have been evaluated.

Bottom-up approaches, such as inkjet printing of YBCO filaments on buffer layer [14,15], as well as selective buffer layer removal prior to YBCO deposition [16], have also been demonstrated as viable methods for AC loss reduction. While all of these techniques achieve the goal of AC loss reduction, they differ in the level of complexity which has a direct impact on throughput and cost, as well as on other aspects such as the degree of critical current degradation, amount of coupling losses and mechanical integrity of the tape. For example, techniques such as wet or dry etching using a photoresist mask are relatively difficult to control and can cause undercuts in the YBCO layer that can degrade \( I_c \) as well mechanical properties [11]. On the other hand, filamentization can lead to high coupling losses, if the resistivity of the substrate and/or any material that may be present between the filaments is low [17]. For all applications requiring a copper stabilizer, non-filamentized, low resistivity copper deposited on the filaments can lead to very high levels of coupling losses, thereby degrading the beneficial effect of HTS filamentization. It is therefore necessary to filamentize the stabilizer layer as well, which, to date, still stands out as an unsolved problem. In addition, filamentization of the shunt/stabilizer layer can also greatly reduce the contribution of eddy current loss component to the total AC loss.

The creation of a highly resistive barrier between filaments without degrading the superconducting properties is of high importance for reduction of coupling losses generated by current transfer between superconductive filaments through the barrier [6,18]. In cases where filamentization is achieved by selective removal of the HTS layer, the conductive barrier typically involves...
the conducting path through the substrate, and the coupling losses are governed by the resistivity of the substrate in the vicinity of the grooves. If the resistance of the material in contact with the grooves is low, the coupling loss can be extensive, leading to an increase in total AC losses to unacceptable levels even after filamentation.

The striation of the stabilizer layer is challenging due to its relatively high combined thickness (which, depending on the application, can exceed 10 µm). Although some of the aforementioned techniques have also been used to striate the shunt layer together with the HTS film, many difficulties were observed, such as redeposition of the ablated material on the grooves, discontinuous cuts due to the thickness of the stabilizer layer, as well as reduction in \( I_C \) due to various reasons including the diffusion of etchant into REBCO layer, creation of oxygen deficiency near filament edges due to laser exposure, etc. [9,11,13,18,19].

In this work, we focus on the development of a striation technique that addresses the issues of HTS striation, stabilizer filamentization, groove resistivity and cost/scalability of the approach. The method consists of several simple, cost-effective and well-controllable techniques, combining top-down mechanical scribing, bottom-up electroplating and control of groove resistivity by formation of an oxide layer on striations. The resulting tape is fully filamentized with respect to both HTS and stabilizer layers, with highly resistive grooves separating the filaments. This architecture results in not only reduction of hysteretic losses, but also in reduced coupling and eddy current losses, while incorporating all the benefits of the stabilizer.

### 2. Sample preparation and experimental

#### 2.1. Striated and control samples

The starting coated conductors used in this work were produced by SuperPower Inc. The conductor architecture consists of buffer layers of alumina, yttria, MgO and LaMnO\(_3\) (LMO), deposited on 12 mm wide, non-magnetic electro-polished Hastelloy substrate followed by deposition of \( \sim \)0.85 µm thick RE–Ba–Cu–O (REBCO, RE = rare-earth) by metal organic chemical vapor deposition (MOCVD) [1,20]. The superconducting film was capped by a 1–2 µm annealed Ag stabilizer. Table 1 provides a summary of the tape properties. All samples used in this study were cut from the same tape reel. Six samples, labeled S1–S6 in this manuscript, were investigated. Samples S3 and S4 were control samples with no striations, where S3 was a completely untreated sample and S4 was electroplated with 11 µm of copper. Samples S1, S2, S5 and S6 were identically striated using mechanical striation. In each sample, 11 straight scribes were created, resulting in twelve 1 mm wide superconducting filaments. A schematic representation of mechanical striation is shown in Fig. 1. The striation was done with a custom-made system that incorporates a diamond-tip scriber, manipulated by an actuator to maintain the load exerted by the scribe on the tape constant, a reel-to-reel type motion system and a tip positioning system to vary the location of the tip along tape width. The 11 striations were made consecutively using multiple passes, but the concept can be extended to involve simultaneous scribing of all grooves in one pass. The load was controlled such that the striation process resulted in complete removal of Ag, HTS and buffer stack. Shown in Fig. 2 are optical and Scanning Electron Microscope (SEM) images of striations on sample S5, where the cross-cut in Fig. 2b was done using Focused Ion Beam (FIB) to reveal the cross section of the groove and the surrounding filaments. An optical image of the 1 mm wide filaments and the surrounding grooves is shown in Fig. 2a. The width and depth of the striations varied from 35 to 55 µm and 7–12 µm, respectively, depending on the load on the diamond tip. The groove shown in Fig. 2b has width and depth of about 45 and 10 µm, respectively. The length of each sample was about 130 mm. The details of the cross-section of the groove, revealing the layered structure of the filaments are shown in Fig. 2c, where the substrate, buffer, REBCO and silver layers can be readily identified. The thickness of the REBCO layer was measured to be \( \sim \)0.85 µm. It can be seen from Fig. 2b and c that silver was pushed to the edge during scribing. Furthermore, the figures reveal that silver and Hastelloy are not smeared to the buffer edge or on the surface of the groove, which is a feature reported on samples striated by laser ablation [19,21–23]. The total amount of REBCO removed across the width of the samples by making 11 striations is about 4–6% of the total width.

#### 2.2. \( I_C \) and \( T_C \) measurements

A summary of the critical current and temperature (\( I_C \) and \( T_C \)) measurements is given in Table 1. A standard four-probe method at 77 K was employed for \( I_C \) measurements using a 1 µV/cm voltage criterion. The configuration of voltage and current taps for total \( I_C \) measurement is schematically shown in Fig. 3. Two thin silver tapes were soldered to each individual filament along the width of the tape to act as voltage taps, in order to simultaneously detect voltage drop from all filaments. In addition, a different configuration, as shown in Fig. 4, was implemented to measure individual \( I_C \) of each filament. In this configuration, we first measured the total \( I_C \) of the tape including all filaments, as shown in Fig. 4a, after which the current tap was consecutively cut and re-soldered to eliminate one filament at a time. Since the length of each filament differed from one to the other by 0.5 cm on each side, a new current tap could be soldered such to eliminate the longer filaments as shown in Fig. 4b. After re-soldering the new current taps, the \( I_C \) of the remaining filaments was measured while keeping the voltage taps intact. This process was continued until the \( I_C \) of the last (shortest) filament was measured.

Critical temperature measurements were performed using an inductive susceptibility technique with a setup consisting of excitation and pickup coils, a DT-470 silicon diode temperature sensor and a lock-in amplifier. Temperature was varied by allowing the samples to slowly heat up from 77 K in the neck of a liquid nitrogen dewar. The samples, coils and temperature sensor were mounted on a copper block to provide uniform temperature distribution across the sensor and the sample.

### Table 1

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Critical current (A)</th>
<th>Critical temperature (K)</th>
<th>Electroplating</th>
<th>Filamentization</th>
<th>Oxygen annealing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>196</td>
<td>91.3</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>S2</td>
<td>194</td>
<td>91.9</td>
<td>11 µm Cu</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>S3</td>
<td>210</td>
<td>92.0</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S4</td>
<td>220</td>
<td>91.1</td>
<td>11 µm Cu</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S5</td>
<td>200</td>
<td>90.9</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>S6</td>
<td>193</td>
<td>91.4</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

![Fig. 1. Schematic representation of tape architecture achieved using the present approach.](image)
2.3. AC loss measurements

Magnetization AC loss measurements were performed using an axial solenoid excitation coil coupled to an AC power source and a compensated pickup coil at liquid nitrogen temperature (77 K). The pickup coil was located inside the excitation solenoid, and the out of phase component was extracted using a lock-in amplifier. More detailed information can be found in [12]. AC loss measurements were performed on 44 mm long sections cut from the middle of the samples used for $I_c$ measurements, in order to eliminate the effect of any possible variation in properties along sample length.

3. Oxidation and electroplating

Coupling loss is generated by current flow between superconductive filaments through a resistive path [9,18,22–24], which in our case is the Hastelloy substrate. As increasing the resistivity of the link between the filaments reduces the coupling loss, filamentized tapes were post-annealed/oxidized at 650 °C in oxygen atmosphere in order to create a highly resistive oxide layer on the groove (we call this process oxidation in this paper). This approach has also been investigated in [18,23]. However, the benefits of oxidation extend beyond AC loss reduction, as the high resistivity of the striations can be utilized to prevent electrodeposition of copper stabilizer on the grooves. Utilizing this fact, an electroplating approach was developed to selectively deposit copper stabilizer only on filaments, thereby avoiding any re-coupling of the filaments that would occur if copper was deposited on the grooves.

In order to examine the effect of oxidation alone on AC loss, samples S5 and S6 were prepared identically (filamentization with no electroplating), except for the oxidation step which was applied only to sample S6. Furthermore, in order to evaluate the effect of copper plating, samples S1 and S2 were prepared with filamentization and oxidation, but electroplating was applied only to sample S2. Since the samples S6 and S1 were subjected to identical treatments, the repeatability of the striation process can also be
confirmed by comparing the results from these two samples. Fig. 5 shows a FIB cross-section of an edge between a filament (left) and a groove (right) of sample S2 after oxidation and copper electroplating. The additional visible layer of platinum was deposited just before FIB ion milling to act as a protective layer. The hump at the edge between the filament and the groove results from a plastically deformed region of the Hastelloy substrate, which extends approximately 10–15 μm on the filament side. The figure indicates that the oxide layer formation starts right from the termination of the buffer layer and extends across the entire groove area. The corresponding TEM image of the right-hand side of the same area cut from the hump is shown in Fig. 6, and confirms the presence of a polycrystalline oxide layer on the groove surface. The thickness of this oxide layer was measured to be between 300 and 350 nm. The nominal chemical composition of Hastelloy consists of 15 wt.% Mo, 15 wt.% Cr, 4 wt.% Fe, 3 wt.% W, and 2.5 wt.% Mn, while the rest is Ni [25]. Therefore, it is likely that this layer consists of oxides such as NiO, Cr2O3 and Mo2O3, and possibly compound oxides such as spinels, NiO2Cr2O4 [18].

3.1. Selective electroplating

If the resistance of the groove material is made sufficiently high, selective electroplating of thick copper stabilizer can be accomplished. Accordingly, a fully-stabilized conductor can be achieved without impact on AC loss. A thick copper stabilizer is needed for a wide variety of applications. Currently, there are no well-established approaches to make multifilamentary coated conductor with filamentization of a thick copper stabilizer. A stabilizer removal approach has been reported for conductors with a thick silver stabilizer layer [9,11,23]. The reported problems associated with this approach include re-deposition of material on the groove or incomplete removal of the layer, which can cause significant increase in coupling losses. An important distinction in our technique is that instead of etching a thick stabilizer or ablating, copper was electroplated selectively only on the filaments using a copper nitrate (Cu(NO3)2) solution. This was possible because of the increased resistivity of the groove after oxidation.

Optical microscopy, FIB-SEM and camera images of our filamentized conductor are presented in Figs. 7 and 8. Optical images of samples before and after copper electroplating (S1 and S2, respectively) are shown in Fig. 7a and in Fig. 7b, respectively. The grooves are clearly visible both before and after electroplating. A FIB cross-section, shown Fig. 7c, reveals only minor discontinuous, island-like formation of small Cu particles on the grooves. After electroplating, the width of the grooves was found to decrease from 48 μm to 25 μm due to copper deposition on the sides of filaments, i.e., in the direction perpendicular to the filaments. As the thickness of electroplated copper is increased, it is expected that the lateral growth will eventually cause the deposits to merge and eventually bridge the grooves, which would correspond to the upper limit for copper thickness of this method. Such a bridging should be avoided because it might drastically increase coupling loss. This limit can be controlled by increasing the width of the grooves (through control of scribing load), at the expense of somewhat reduced fraction of the superconducting cross section. However, the practically achievable thickness using this method appears to be higher than needed for most of the current applications known to the authors. The copper thickness in this sample was found to be ~11 μm and highly uniform along both the width and length of the filaments. A control sample (S4) was also copper plated under the same conditions as sample S2 and was found to exhibit the same thickness and uniformity.

A complete cross-sectional profile of sample S2 is presented in the optical micrograph shown in Fig. 8. The top layer seen in the figure is electroplated copper, the intermediate black layer represents the REBCO/buffer films and the bottom layer is the 50 μm Hastelloy substrate. The groove between the filaments is seen to extend all the way into the substrate after removal of REBCO and silver stabilizer layers, and the depth of the groove is about 20 μm, measured from the top copper surface.

4. Results and discussion

4.1. Critical current and critical temperature

A summary of Tc and Ic results are given in Table 1. All measurements were done at 77 K. The critical temperature of the samples was found to be fairly uniform, indicating no detrimental effects of copper plating and post-annealing on Tc. The lowest Tc was 90.9 K for S5 and the highest was 92.0 K for S3. The Ic values were also found to be close to each other, and an average of ~8% reduction in Ic was seen after striation. The Ic reduction due to REBCO layer removal should be 4–6%, and the additional 3–4% reduction might be due to slightly varying width of the filaments and possibly from a slight influence of post-oxidation and/or electroplating. The Ic for the sample with the highest Ic is about $2.16 \times 10^6$ A/cm², while that for the sample with the lowest Ic is about $1.97 \times 10^5$ A/cm².
cm². The distribution of $I_c$ across filament width is shown in Fig. 9. The figure indicates that the $I_c$ drops considerably towards the edges of the tape, while it is relatively uniform in the middle. This characteristic is most likely intrinsic to the as-received tape, rather than due to the filamentization/plating process, as a similar behavior has been reported in other studies [13,19].

4.2. AC loss in perpendicular field

The magnetization loss of the samples was measured at frequencies varying from 45 to 500 Hz at 77 K. Brandt and Indenbom have investigated current and magnetic field distribution in a superconductive isolated strip and derived an expression for AC power loss per cycle per length, [J/m/cycle], in the presence of perpendicular applied AC magnetic field of amplitude, $H_a$ [7].

$$P = \mu_0 w l_c H_a \left( \frac{2}{x} \right) \ln \cos h(x) - \tan h(x)$$

(1)

where $x = \pi H_a w / I_c$, $w$ is the width of the filament (or tape width for non-striated samples), $I_c$ is the critical current, and $\mu_0 = 4\pi \times 10^{-7} [1]$ is the permeability of free space. In this expression, the effect of the neighboring filaments is neglected. In a striated conductor, the magnetic field distribution is affected by the field concentration in the non-superconducting grooves that leads to a change in magnetization AC loss performance of striated samples at relatively low field amplitudes due to the magnetic coupling which is not dependent on electrical resistivity of groove material, and little can be done by changing separation between filaments [12]. For this reason, the magnetization AC loss calculated using the Brandt–Indenbom model will include an error when the applied field magnitude is small due to neglecting the influence of the neighboring filaments. Mawatari [8] has derived a model by considering an infinite array of superconducting filaments. However, the Brandt–Indenbom derivation is used in this work for the convenience of comparison with other studies.

The magnetization AC losses loss per cycle, [J/m/cycle], vs. applied AC field, rms, for the striated samples S1 and S2 are presented in Fig. 10a and b, respectively, and compared with the limits predicted by the Brandt–Indenbom model in log scale. In the figures, the dashed line labeled “B–I, Str.” is calculated for a 12-filament
sample and the continuous line, labeled “B–I, non-Str.” is calculated for the non-striated reference sample using the model. Both samples, S1 in Fig. 10a and S2 in Fig. 10b, are seen to follow exactly the same AC loss performance which indicates that the contribution of electroplated copper on S2 has no effect on AC loss performance of the sample. Sample S6 (not shown in Fig. 10 for clarity) also follows the same trend as samples S1 and S2, which is an indication that the striation procedure is repeatable since the processing conditions for S1 and S6 were identical. It is important to note that the magnetization AC losses of striated samples S1, S2 and S6 are linearly dependent on frequency and that the curves in Fig. 10a and b coincide after normalization by their respected frequencies (i.e., loss per cycle). This is an indication that the main contribution to magnetization AC loss is hysteretic. A good agreement between the model (B–I, Str.) and the experimental data is seen in the high-field region. However, in the low field region, the experimentally measured loss of striated samples deviates towards the calculated values for the non-striated case (B–I, non-Str.). This deviation has been regularly reported in other studies [9,12,16], and might be attributed to non-uniform lateral $j_c$ distribution (see Fig. 9) and magnetic coupling effect on the loss performance. Furthermore, the validity of the assumption of linear proportionality of hysteretic loss with respect to width at very low fields has been addressed and analyzed in view of distortion of field lines that leads magnetic coupling loss [12].

In Fig. 11, the AC losses per length, [W/m], of samples S1–S4 are compared as a function of frequency at different AC rms field magnitudes. From Fig. 11a, the magnetization loss is linearly dependent on frequency, which indicates that the coupling contribution is negligible in both striated samples, i.e., both before and after electroplating. This is an important feature that demonstrates that the present striation/electroplating approach does not result in any appreciable additional loss. On the other hand, as can be seen in Fig. 11b, copper electroplating on the non-striated sample S4 results in additional AC loss. As expected, a comparison between control samples S4 and S3 in Fig. 11b reveals an additional eddy current contribution present in the electroplated control sample S4 compared to the completely untreated sample S3.

A comparison of magnetization AC loss per cycle as a function of field amplitude on a linear scale is shown Fig. 12, summarizing the individual effects of striation and electroplating on samples S1–S4. An inset is also provided to reveal more details for samples S1 and S2. It is apparent that electroplating of the striated sample (S2) has no appreciable effect on total AC loss compared to the striated-only sample (S1) on a linear scale of interest for applications. Actually as can be seen from the inset, the loss curves almost coincide. On the other hand, there is a significant contribution coming from electroplating on the non-striated sample S4 relative to the completely untreated reference sample S3. The reduction in AC loss due to striation is at least 11 times before copper electroplating (close to the theoretically estimated value) and at least 13 times after copper electroplating at relatively high field amplitudes. This additional loss reduction is likely due to the reduced eddy current loss achieved by copper filamentization since the eddy current contribution is proportional to the third power of the width [6].
High frequency measurements can reveal coupling loss clearly since the coupling loss has a quadratic dependence on frequency. Levin et al., [22] defined a term called break-even sweep rate in order to determine the quality of striation and contribution of coupling and hysteretic loss to total magnetization AC losses.

\[ R = \frac{\lambda_1}{\lambda_2} \]  

where \( \lambda_1 \approx w_0 \) and \( \lambda_2 = 2Ld_0w/W\rho l_c \), \( w_0 \) is filament width, \( W \) is sample width, \( L \) is sample length, \( d_0 \) is metal layer thickness and \( \rho \) is the effective resistivity. The coefficients \( \lambda_1 \) and \( \lambda_2 \) are independent of sweep rate and only related to the sample properties. The first term, \( \lambda_1 \), represents the hysteretic loss while the second, \( \lambda_2 \), represents the coupling loss. In this analysis, the eddy current component is neglected due to its significant reduction achieved by the filamentization of the stabilizer layer. Using these two constants, the point where the coupling loss is equal to magnetization loss (break-even sweep rate) can be calculated. In other words, if \( R \) is high, the coupling contribution to total magnetization AC loss is low. The total loss per length in terms of hysteretic, \( P_{st}^h \) and coupling, \( P_{st}^c \), loss can also be expressed as \[ P_{st} = P_{st}^h + P_{st}^c = A L B_{0f} f \]  

where \( A = \lambda_1 + 2\lambda_2 f \) is the “specific loss” (loss per cycle per unit length normalized by \( I_c B_0 \), in units of length), \( B_0 \) is the peak value of applied AC field and \( f \) is frequency. \( A \) can also be interpreted as the effective filament width, or, in other words, as an indicator of the quality of the striation procedure.

As it has been mentioned earlier, samples S5 and S6 were prepared to examine the effect of the oxide layer created on the coupling loss. Shown in Fig. 13 is the specific loss, \( A \), with respect to sweep rate, which in turn indicates the effective filament width. The linear fit shown by the solid line in Fig. 13a is calculated for 200 Hz for S5 according to the definition of specific loss, although it was also confirmed for other frequencies. The slope of the linear fit of the data is related to the coupling loss while the intercept of the linear fit with \( y \) axis is related to the hysteresis loss. Accurate estimate of the slope and intercept is much more difficult for the data obtained from samples containing an oxide layer in the grooves because of the very low slope of the data and the corresponding strong effect of noise. However, even with the increased slope/intercept fit uncertainty for the oxidized samples, it is obvious from Fig. 13a that after oxidation, the coupling loss is almost completely suppressed compared to the non-oxidized sample, as evidenced by the drastic decrease in slope. The effective width of the filaments, as estimated from the linear fits, is 1.06 and 0.98 mm for the samples before (S5) and after (S6) oxidation, respectively, which is in reasonable agreement with the filament width measured from optical or SEM images. These values also indicate good quality of striations. The calculated break-even sweep rate, \( R \), for the sample before oxygenation (S5) at 200 Hz is found to be about 15 T/s.

The data used in Fig. 13b is the same as that in Figs. 10a and b for S1 and S2, but plotted in a different way, as explained above, to show the effect of electroplating on striated and oxidized samples. Some of the frequencies are excluded from the plot for clarity. It is apparent that the results before (S1) and after (S2) electroplating of 11 µm copper coincide. This indicates an absence of appreciable coupling loss contribution from electroplating. The coupling loss is inversely proportional to the resistivity of the normal metal [6]. If there were any significant electroplating copper on the groove in S2, an increase in coupling loss would be expected due to the low resistivity of copper, resulting in an increase in the slope of the linear part of the data for S2 in Fig. 13b. Furthermore, data for samples S1 and S6 shown in Fig. 13a and b give an indication of good repeatability of the filamentization/oxidation process, as they were subjected to identical striation/oxidation conditions.

5. Conclusions

We have developed and presented a method for full filamentization of both REBCO and stabilizer layers in HTS coated...
conductors utilizing a combined top-down scribing process, striation oxidation and bottom-up electroplating. In this method, the Ag shunt, REBCO layer and buffer stack were removed by mechanical striation using a diamond tip. 11 striations were made over the 12 mm tape width, which was followed by post-annealing at 650 °C in oxygen atmosphere to create a highly resistive oxide layer on the grooves. A thick stabilizer copper layer was then selectively electroplated only on filaments while the grooves remained free of electrodeposited copper due to the creation of the resistive oxide layer.

The coupling losses have been significantly reduced both due to the absence of electroplated copper on the grooves and increased resistivity of the coupling path across the grooves due to the formation of the oxide layer. In addition, eddy current losses were also significantly reduced due to copper filamentization. The critical current of the parent tape did not degrade appreciably beyond the expected decrease due to the reduced cross section resulting from striation of the HTS material. The reduction in AC loss in the striated samples compared to equivalent non-striated samples is at least 11 times before electroplating of copper and at least 13 times after electroplating. A twofold decrease in AC loss is achieved possibly just by reduction of eddy current losses through the filamentization of the copper stabilizer.

Acknowledgments

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References


