Using Hall Effect Measurements to Determine Thin Metal Deposition Thickness

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This past summer Professor Msall and I focused on using metal deposition to produce thin, high quality layers of gold suitable to be used in manufacturing inter-digital transducers (IDTs). The IDT is a microscopic circuit ubiquitous in electronic devices. It is built from layers of metal that are billionths of a meter thick and which are deposited onto a piezoelectric substrate. A circuit can be created with the metal layers using photolithography, a process that uses a layer of masking to preserve some metal in a circuit pattern while removing the rest. A completed IDT circuit uses the electric and vibrational properties of the substrate to launch vibrational waves through the substrate. The metal deposition process used to manufacture the IDT must be reliable and must produce high quality depositions. Depositions that are too thick or too thin, for example, interact differently with substrates and produce unusable vibrational waves.

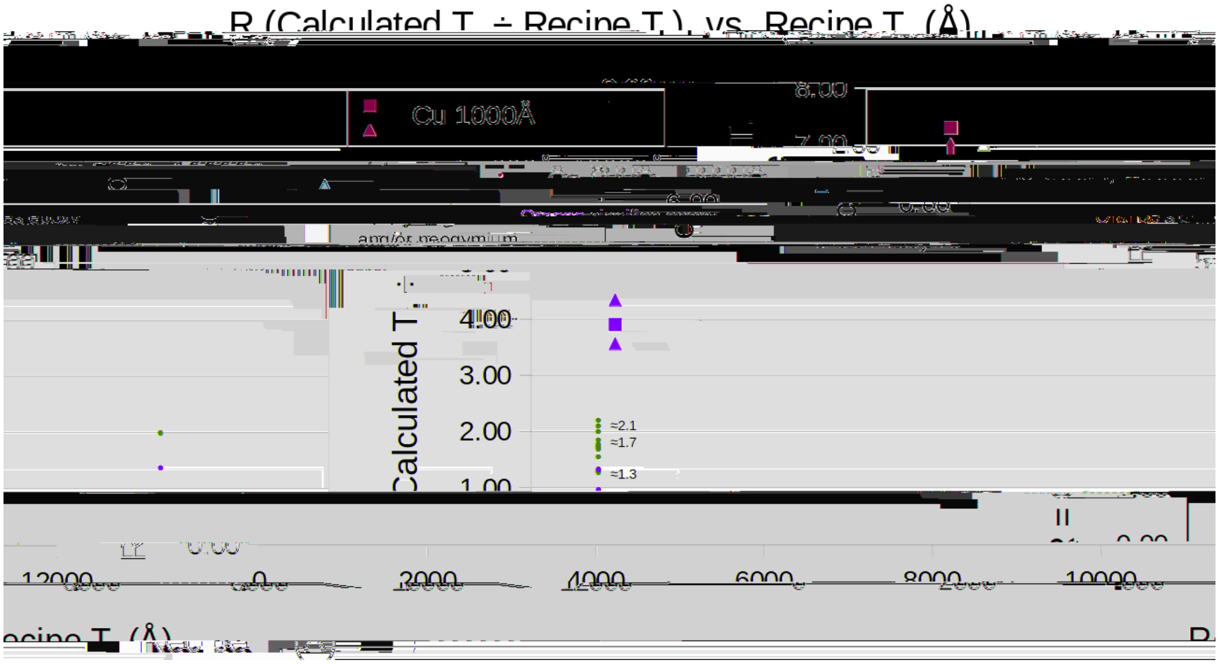
We worked with the Physics Department's BT300 thin-layer metal deposition system to ensure the actual thickness of its depositions matched the thickness programmed into its “recipes.” I learned how to use the BT300 and deposited layers of copper and gold onto glass slides. Conventional measuring tools cannot be used to determine the thickness of the depositions; rather, other characteristics of the deposition must be determined and then related to the deposition thickness. The Hall Effect experiment yields data that can be used to calculate the thickness of a layer of metal. The Hall Effect, discovered by Edwin Hall '1875, relates the layer's thickness to the known electron density of the metal as well as to measured experimental values of an electric current, electric voltage, and a surrounding magnetic field. To form a layer in the shape of the “Hall bar” necessary for experiment, we placed stencils on the glass slides prior to the deposition. The stencil is lifted off after the deposition, and the inverse of the stencil forms the shape of the Hall bar.

We set up each Hall bar deposition sample in a magnetic field and used a Lock-In Amplifier to send alternating electric current through the bar and simultaneously measure its “Hall voltage.” Once we determined the electric current, Hall voltage, and surrounding magnetic field, we calculated the deposition thickness, and then compared it to the thickness programmed in the recipe. We varied the current sent through the Hall bar and calculated the thickness for each value of current, which gives a more accurate average thickness measurement for each Hall bar.

We determined that the BT300 deposits gold more accurately than it does copper, and that it always overdeposits. The graph below shows the ratio of our calculated thickness to the recipe thickness ($R_{\text{ideal}} = 1$) for depositions of varying thickness. For the gold bars, $R = 1{:}67$ with a standard deviation about the mean of $= 0{:}3$, with $R_{\text{copper}} = 5{:}4 \quad 1{:}51$. Sources of error for this difference between gold and copper include the possibility that a value in the BT300 is incorrectly programmed, as well as the fact that copper oxidizes faster than gold; oxidized copper is likely to yield a smaller measured Hall voltage compared to gold, and thus a greater calculated thickness.

The graph also indicates that using conductive epoxy to make wire contacts with the bar, instead of soft indium metal, as well as using a permanent magnet to generate the magnetic field, reduce R. The permanent magnet brought R for the two gold bars down from averages of $1{:}3$ and $1{:}7$ to $0{:}96$ and $1{:}3$, respectively. For the copper bars, R was brought down from averages of $7{:}3$ and $6{:}7$ to $3{:}9$ and $4{:}0$, respectively. The physical positions of the slides during the deposition is also correlated with changes in R: our three 800A gold bars, made during the same deposition, each have distinct R: $1{:}3 \quad 0{:}12;\ 1{:}7 \quad 0{:}16;$ and $2{:}1 \quad 0{:}07$. The bars' positions during the deposition, combined with the varying rotational speed of the tray holding the slides, are the most plausible factors behind this difference in R.

A final source of error includes the Hall bar stencil. The 1000A copper bar (triangular data points), which reached the very high $R = 7$, had visibly fuzzy edges due to an inadequate stencil. Almost all Hall bars were made using stencils that were not perfectly symmetric and which did not have smooth, sharp edges; these physical defects affect how the Hall voltage forms across the bar,



Various smaller projects were done throughout the summer. We spoke with the Department Machinist about machining a stencil and helped design a rigid, symmetric, and smooth-edged stencil. Another project involved Professor Battle's research; he had electronic pins that needed to be coated with a layer of gold to protect them from oxidization and wear. I designed and drafted a tray to hold the pins in place during the deposition, and researched industry standards for protective gold layers. We then deposited 1 μm the concensus of gold onto the pins. I also ordered compressed air, tinfoil, and protective clothing for the clean room which met clean room standards.

Future research should verify the extent to which the error discussed above meaningfully affects Hall voltage measurements. All trials should use a permanent magnet, and should compare indium contacts with epoxy contacts. Copper's oxidization should be accounted for, and the BT300's pre-programmed recipe values should be examined. Finally, the position of the bars during deposition should be recorded to determine if a difference in position is correlated with a difference in calculated thickness.

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