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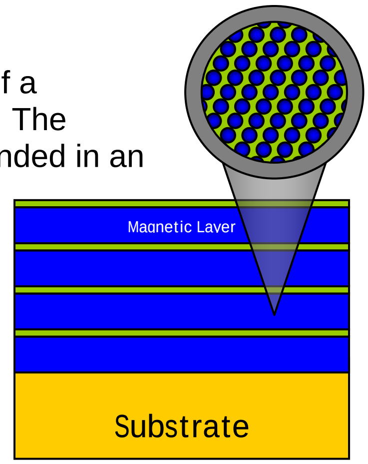
The object of this project is to provide a material for another project that seeks to make a small, high-frequency inductor. Since the creation of inductors, the magnetic field generated inside the coil of wire has been a limit. An attempted solution to this problem was to put a magnet inside the inductor in the hopes of opposing the generated magnetic field, but regular magnets are only effective when the current in the inductor has low frequency. There is a law stating that inductor size and frequency of current are inversely proportional. In the quest to make everything smaller, it is desirable to run a higher frequency of current through the inductor. To do this, it is necessary to find a better magnetic material to counteract the field generated by this higher frequency. Finding that material is the purpose of this project.

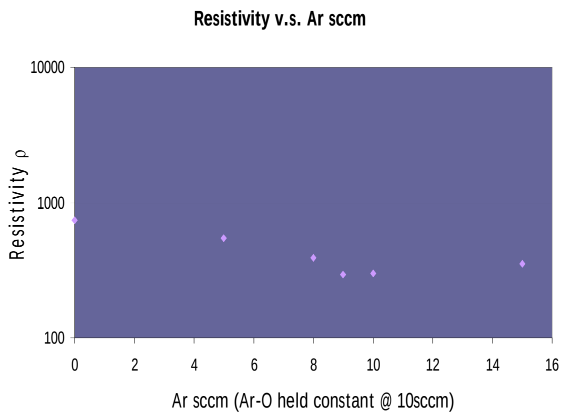
The process for making this material is somewhat complicated. The finished film is alternating thin layers of a magnetic material with thinner layers of zirconium oxide. The magnetic material is in fact tiny particles of Cobalt suspended in an insulating zirconium oxide layer. These particles are primarily individual magnetic domains which are effective in generating the desired magnetic properties of this material.

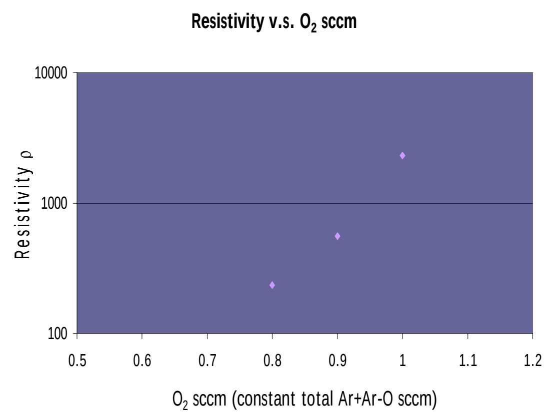


The material is made in a sputtering machine. This is a vacuum chamber with a table and cathodes inside. On each cathode is a target, in this case Zirconium and Cobalt. First, the substrate is secured to the table and the chamber is pumped to a high vacuum on the order of 10^-7 torr. Then the chamber is flooded with specific amounts of argon gas and a 90%Ar+10%O2 mixture. Next, a voltage is established across the cathode and the table, knocking electrons off the argon atoms and creating plasma. This plasma in turn knocks atoms off the target which land on the substrate, creating a thin film of the material. Recipes, like little programs, are used to create the film according to certain specifications. Regulated factors include: lengths of time each material is sputtered, power on each cathode, and amounts of Ar and ArO in each step.

Magnetic Properties and Stress are the most important characteristics to be refined in the film. “Good Magnetic Properties” basically means that the material functions properly. Minimum hysteresis loss and high resistivity are desirable. I have not observed a trend in the changing of the bh loops which seem to be affected substantially by both Oxygen and Argon flow rate changes. Resistivity is affected primarily by the flow rate of Oxygen gas in the chamber during deposition, but the flow rate of Argon gas also has a minor effect. The following graphs (Resistivity v.s. Ar sccm and Resistivity v.s. O_2 sccm) demonstrate this trend for resistivity. Note that both use the same logarithmic scale, and that there is very little change in resistivity for varied Argon flow rates.

Stress is caused by a sputter pressure that is too high or low for the film. Experimentally, the sputter pressure seems to be controlled by the total flow rate of gas; more gas gives a higher sputter pressure. A low sputter pressure shows





negative stress, while a high sputter pressure shows positive stress. Oxygen tends to lower the sputter pressure, so a sample sputtered with 0.5sccm Oxygen as 5sccm 90%Ar+10%O_2 and 14sccm Ar would likely show positive stress, while a sample sputtered with a total gas flow of 1.2sccm Oxygen as 12sccm 90%Ar+10%O2, and 7sccm Ar would likely show negative stress, even though the total flow rate of gases adds to 19 in both samples. Unfortunately, although this trend has held for a few samples, there is not enough data to back or disprove this claim.

Because the magnetic properties are generally affected primarily by the oxygen flow rate while stress is affected by both, the experiment progresses in a very specific order. Every time the cathode target is changed, the old recipes often are no longer useful. One recipe that has worked well as a starting point for new targets uses 9sccm Ar and 10sccm 90%Ar+10%O_2 mixture. After running this sample on a new target, the next step is to adjust the flow rate of Ar-O mixture. It is generally sufficient to try a few flow rates very close to the initial guess, and the sample with the best magnetic properties is selected. After the magnetic properties are refined, the pure Ar flow rate is adjusted to arrive at a level of minimum stress. If the material shows positive curvature, the Ar flow rate is decreased; if the material shows negative curvature then the Ar flow rate is increased. After sputtering a thin film with good magnetic properties and good stress, a thicker film is attempted. Sometimes, thickening the film ruins the magnetic properties, or more often it ruins the stress. The sputtering machine is only capable of quantized flow rate changes, so if the desired Ar flow rate in the magnetic layers is between 8sccm and 9sccm, a possible solution is to alternate 8sccm layers with 9sccm layers.

Several problems have arisen over the course of this summer research. The most frustrating problem is that each new target seems to need its own recipe. Targets cannot be thicker than about 60mils or else they are too resistive and the plasma cannot be established in the chamber with a useful DC current. One of these targets can only sputter about 15μm of film before it must be replaced. Thus if it takes too many runs to determine the recipe, there may not be enough target yet to try a thicker film when the best recipe is finally found.

Also, if there are two potentially good recipes, both cannot be tested as thick films.

Another frustrating issue has been the search for the perfect substrate. It must be very thin so that as much magnetic material as possible can be packed into the tiny inductor. However, thin substrates tend to be very flexible or very fragile. Much experiment has been done with 3mil polyimide, and it is very difficult to refine the stress enough to feasibly use this flexible material. The best way found so far to make the fan shape is to have a company die cut the fan shape in the polyimide with small connections so that it stays for sputtering and can be removed afterward. Unfortunately, the only company found that is willing to make so small a die cannot put the fans close enough together to make this a feasible solution. It would take 16 targets to get enough fans for a single inductor!

Hoping to avoid the stress issue of polyimide, thin glass has also been used as a substrate. The biggest problems with this approach are that glass does not come thin enough for the desired inductor size, and thin glass is extremely breakable. One solution considered was sputtering the fan shape through a stencil and etching off part of the back glass, down to 1mil of glass substrate. If the film will hold up long enough in unbuffered HF (buffered HF takes too long to etch the class), then this might work, although the resulting pieces would likely be too fragile to lift with tweezers.

If the stress could be minimized enough, it might be possible to forego a substrate altogether. The film could be sputtered through a shadow mask in the fan shape onto a silicon wafer coated with photoresist or some other removable coating. After sputtering, the coating could be removed, allowing the pieces of film to come free with no substrate.

Much was accomplished in the last eight weeks, however there is yet work to be done. Hopefully there will be enough similarity between the next targets to maintain a single recipe throughout, which will allow for that part of the project to be finished soon. Perhaps the most difficult part of this project will remain the seemingly simple task of choosing a substrate. Still, the project has excellent potential.