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Stresses evolution at high temperature (200°C) on the interface of thin films in magnetic components

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Abstract. In the field of electronics, the increase of operating temperatures is a major industrial and scientific challenge because it allows reducing mass and volume of components especially in the aeronautic domain. So minimizing our components reduce masses and the use of cooling systems. For that, the behaviours and interface stresses of our components (in particular magnetic inductors and transformers) that are constituted of one magnetic layer (YIG) or an alumina substrate (Al_2O_3) representing the substrate and a thin copper film are studied at high temperature (200°C). COMSOL Multiphysics is used to simulate our work and to validate our measurements results. In this paper, we will present stresses results according to the geometrical copper parameters necessary for the component fabrication. Results show that stresses increase with temperature and copper's thickness while remaining always lower than 200MPa which is the rupture stress value.

1 Introduction

Nowadays, the world is full of integrated electronics components, some of which are too small. These components operate at a room temperature of 298K but sometimes they are used under conditions of severe temperatures which can reach 473K and more such as in aeronautic transport field where the problems of weight and volume are in question. For example, the engine of an airplane operates at high temperature which can cause damage for components; while the decrease in mass causes a reduction of cooling systems and strengthens the constraints.

However, and for the moment, several studies at high temperature have been made on power electronics converters such as power transistor and their commands but it seems that the passive components have an obvious barrier at the surface, volume, weight... Several patents address the design and implementation of inductors [1- 4] and embedded processors [5-7] but none has worked on high temperature areas.

Our job is then to design and manufacture components in a way that they meet the following criteria:

- Operation in an ambient temperature of 473K
- Collective fabrication
- Dimensions compatible with integration into a power module

This is why the behaviour of materials and stress at the interface of different layers are studied at high temperature including 473K so components can be minimized and still operateat severe temperatures.

This paper is divided into few parts: the first part describes our structure, the second present simulations where temperature is varied from 293K till 523K to study stress at the interface of our layers because when we have a temperature gradient we have energy exchange from one region to another and this phenomena is called heat transfer; the third part represents the characterization and measurements made for stress calculation where we measure samples' curvature radius using a profilometer in order to calculate stresses at interfaces between layers, the fourth part representssimulation and measurement results with a comparison.

2 Sample's preparation

Our samples were made of a thin copper layer which is deposit on an Alumina layer or a magnetic layer particularly YIG with the dimensions shown in table1. The method used for copper deposition is theSputter deposition [8]. Deposition is made for 30 minutes so as to have 5µm of copper. Once structures are realized, they are ready to be annealed at high temperatures and to study material's behaviour and stresses at layer's

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interfaces in order to conclude rupture stress or tensile stress.

Table 1. Structure dimension.

	Substrate	Copper film
Width	5cm	5cm
Depth	2cm	2cm
Height	635µm	5µm

3 Simulations

So the physical model is similar to the one realized in reality as shown in Figure1:

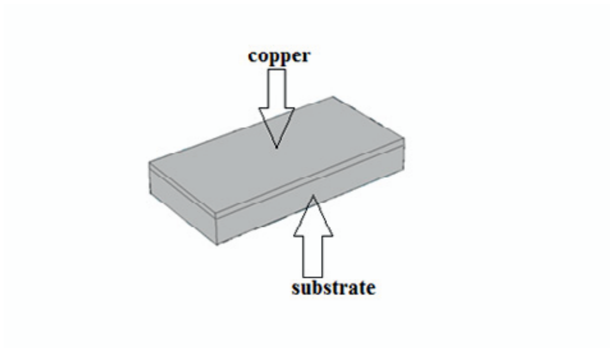

Figure 1. Physical model.

This model is simulated onspecific software calledCOMSOL Multiphysics v4.0 and v4.2 [9]. The COMSOL Multiphysics simulation environment facilitates all the steps in the modeling process – defining your geometry, meshing, specifying your physics, solving, and then visualizing results. It also serves as a platform for the application specific modules.

So the behavior of our structure in function of temperature is studied; temperature is varied from 293K till 523Kwhile geometric parameters are invariables using the heat transfer module. Figure 2 shows structure deformation and Von Mises Stress found in simulation.And stress variations are studied at the interface of our layers in function of temperature. Then copper thickness is varied: 10µm, 30µm and stresses at the interfaceare compared with the ultimate tensile strength which is the adhesion limit.

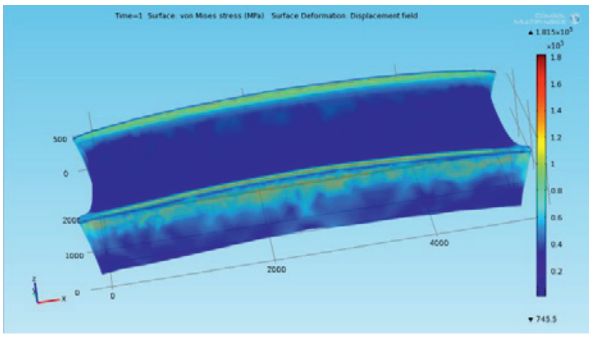

Figure 2. Von Misses Stress and Deformation.

4 Characterization and measurements

In experimental part,the curvature radius of each substrate were measured before deposition with a profilometer, then 5µm of copper were deposited on it, using a sputter coating machine for 30 minutes with 300W of power. Once deposited, the curvature radius of samples is measured again and stress is calculated at the interface using Stoney formula [10]:

$$\sigma = \frac{1}{6}\left(\frac{1}{R} - \frac{1}{R_0}\right) . \frac{E_s}{1-\nu_s} . \frac{d_s^2}{d_f} \qquad (1)$$

Where R is the curvature radius after copper deposition; R_0 is the initial curvature; E_s the substrate Young modulus; υ_s the substrate Poisson's ratio; d_s the substrate thickness and d_f film thickness.
We have to note that this expression is an approximation, whose validity is widely accepted however, under certain assumptions [11-12].

Then, structures are exposedduring 75 minutes to high temperature (473K) in a specific oven that heats till 3273K and it's shown on the Figure3. Once samples are cool, curvature radius are measured again and stress is calculated using the same formula except that in this case R will be the curvature radius after annealing but others parameters will stay the same.

Figure 3. Oven used for annealing.

5 Results

5.1 Simulation

As said before, simulations for different copper thickness (5µm, 10µm and 30µm) were made on COMSOL Multiphysics in function of temperature [298K; 523K] in order to see deformations (Figure3) and study stress between structure's layers.

Figure4 shows Von Mises Stress [13] and Ultimate tensile strength [14-15]at the interface of structure's layers in function of temperature variation.

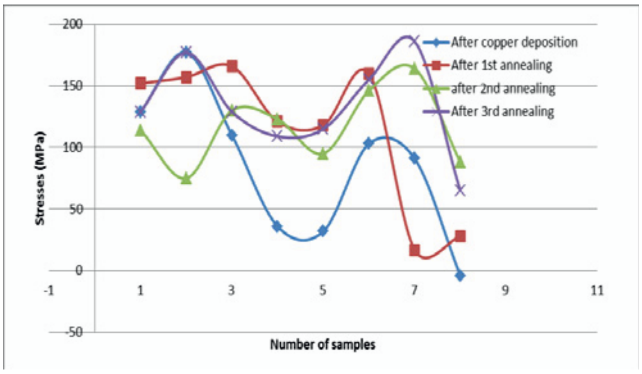

Figure 5. Stresses measured over different samples.

5.2 Comparison between simulation and measurements

In a comparison between simulation results and those experimental, a good agreement between them is shown: According to measurement results, stresses are lower than 0.2 GPa (rupture limit of copper) after copper deposition and when components are annealed at 473K which means that there's no rupture on this temperature, and simulation results showed that at this temperature Von Misses Stress is lower than the Ultimate Tensile Strength, the adhesion limit (see figure 2) so simulations confirm that there is no rupture for this temperature.

One thing to note is the difference in stress results on 473K between simulations and measurements: as shown in Figure2, at 473K and for 5µm of copper Von Mises Stress is equal to 75 MPa, while measurements give 100 MPa in average; this is due to the fact that

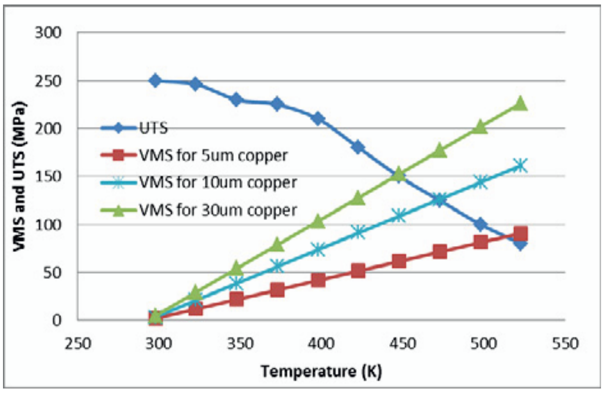

Figure 4. Von Misses Stress and Ultimate tensile strength.

COMSOL does not take in consideration the initial curvature radius of samples. In other words, COMSOL consider that all simulated samples are initially perfect or ideal with an infinite curvature radius.

6 Conclusions

Simulations done on COMSOL Multiphysics show that Von Misses Stress varies with temperature and copper thickness: when temperature increases Von Misses Stress increases and when copper thickness increases Von Misses Stress increases also. In addition, we remark that the Ultimate Tensile Strength depends only on the temperature and copper thickness has no effect on it.

From measurements, only the first annealing has an effect on studied structure, but after that no matter how many times samples will be annealed the stress values will remain approximately the same. And stresses are lower than 0.2GPa which means that samples stand on high temperature and there is no rupture. And it is corroborated with simulation where Ultimate Tensile Strength is lower than 250MPa at room temperature.

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