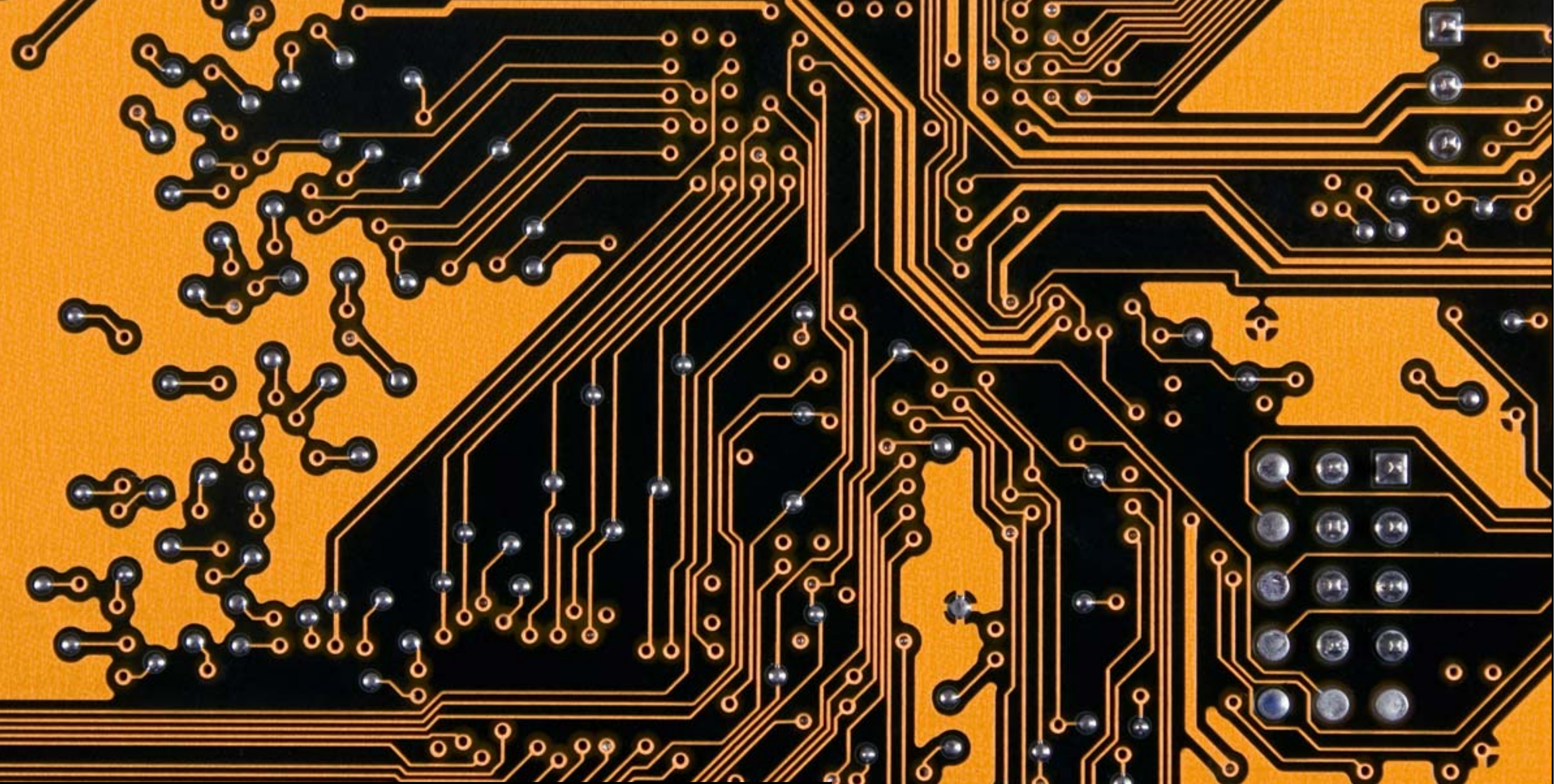

CUSTOMER STORY // ELECTRICAL ENGINEERING

OPTIMIZATION OF MODEL CALIBRATION FOR ANALYZING THE BEHAVIOR OF FILM COPPER

optiSLang provides effective methods of parameter identification to optimize the analysis of film copper produced by Electro-Chemical Deposition (ECD) in the semiconductor industry.

Optimization Task

Metallic thin films often show a different physical behavior than bulk solids made of the same material. This requires the determination of new parameters of corresponding material models. Thin film copper produced by ECD is widely used in the semiconductor industry because of its excellent electrical and thermal conductivity. The functionality of semiconductor products depends strongly on the mechanical performance of ECD-Cu under a broad temperature range. Therefore, the stress-strain response of this special copper is measured at different temperatures. The aim of the optimization was to match the reference signal (bow vs. time) from the experiment with the simulated signal from the FEM calculations.

Methodology

The stress-strain response of this special copper is measured at different temperatures. The wafer curvature approach serves as a standard method. It measures the change of curvature radius due to mismatch in thermal extension coefficients between the film and substrate for a temperature profile. Silicon is often used as a substrate since its mechanical properties are defined and sufficiently known.

In this example, an inelastic material model consisting of seven parameters was validated for ECD copper subjected to cyclic thermal loading (see Fig. 1).

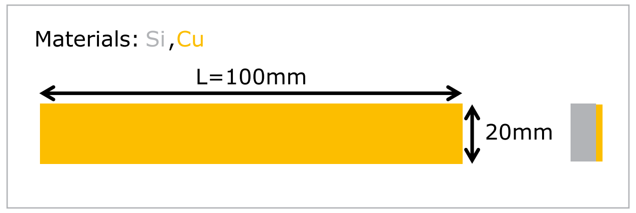

Fig.1: Bimetallic strip in top view and cross section, silicon in grey, copper in yellow

The raw measured quantity was the curvature radius (see Fig. 2). It is usually used for the calculation of the bow (maximal deflection of sample) and stress in the film using Stoney's formula which is valid for the elastic and non-elastic range:

$$\sigma_{Cu} = \frac{E_{Si} h_{Si}^2}{6 h_{Cu}} \frac{1}{R}$$

where σ_{cu} describes the average film stress in the direction of the length side of the strip, h_{Si} is the substrate thickness, R is the radius of the curvature and E_{Si} is the Young's modulus of the substrate.

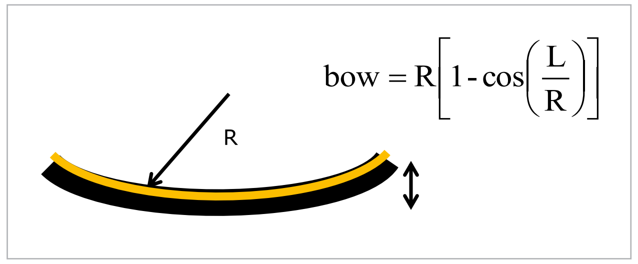

Fig. 2: The Curvature radius of a Cu-Si bimetallic strip is the raw measured quantity. The bow is calculated afterwards and compared with simulation results.

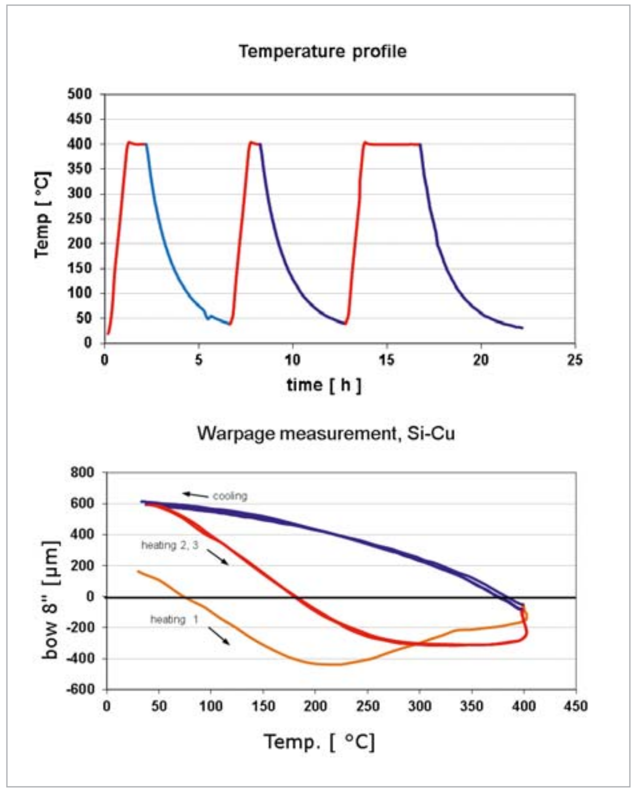

Fig. 3 top: A typical cyclical heating and cooling process during a measurement of a Cu-Si bimetallic strip | bottom: The bow evolution displayed as a function of temperature clearly demonstrates the complex inelastic behavior of ECD copper.

The measurement of the mechanical properties of the Cu-Si bimetallic strip was performed by a cyclical thermal exposure that is illustrated in Fig. 3 top. The corresponding measurement data deduced from the curvature of the substrate is shown in Fig. 3 bottom. Before running the calibration procedure, it had to be decided in which extent each parameter should be changed. For this purpose, gradients of the objective function were manually built as sensitivity measures using MS Excel. Even after achieving a satisfactory result with this method, it was not clear whether the parameter set could be further improved or not. For comparison, the optimization was also conducted with optiSLang applying the least squares approach.

Within one day, the automated optimization was finished after 284 runs of simulation. It could be seen that the agreement of the curves of the automated optimization was significantly better than the agreement of the manual optimization (see Fig. 4).

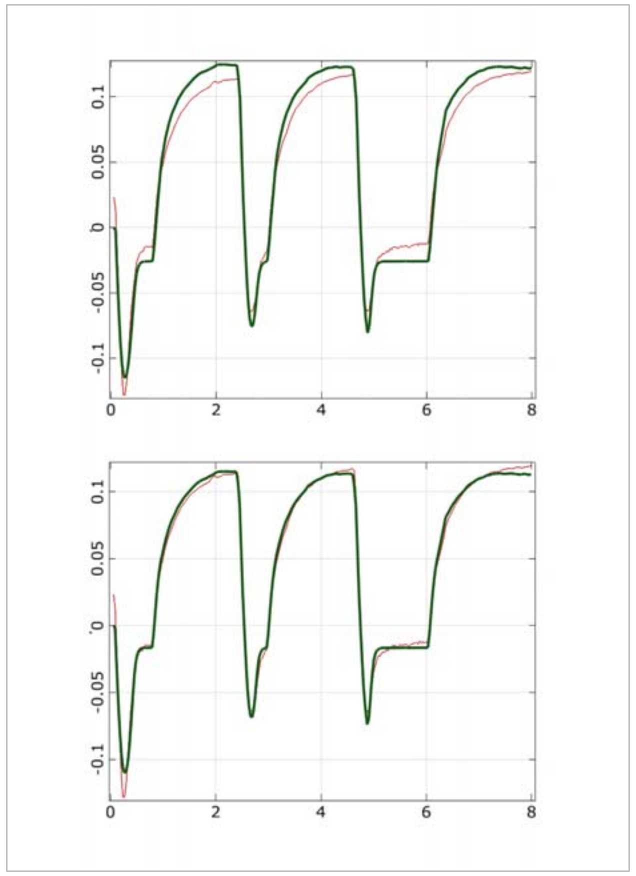

Fig. 4: Bow vs. time. Top panel: The outcome of the manual optimization was a good agreement between reference and simulation signal but with much effort. Bottom panel: The automated optimization resulted in an almost perfect match within a shorter time (green -simulation, red -experiment).

Customer Benefits

A "manual" validation was extremely time-consuming: it took about 3 weeks for 70 simulations. The problem was not necessarily the time needed for one run (it was less than 10 min), but the analysis of results and decision making how to change the parameter values in order to achieve a better calibration to the experimental results. With optiSLang, this procedure was optimized regarding time efficiency and result quality. An additional advantage of using optiSLang was the possibility to repeat the parameter fitting, for example, in the case if some model parameters were deduced from independent experiments. For manual validation, such a situation would be a real no-go criteria, because the simulation engineer would have to start the whole procedure over.

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