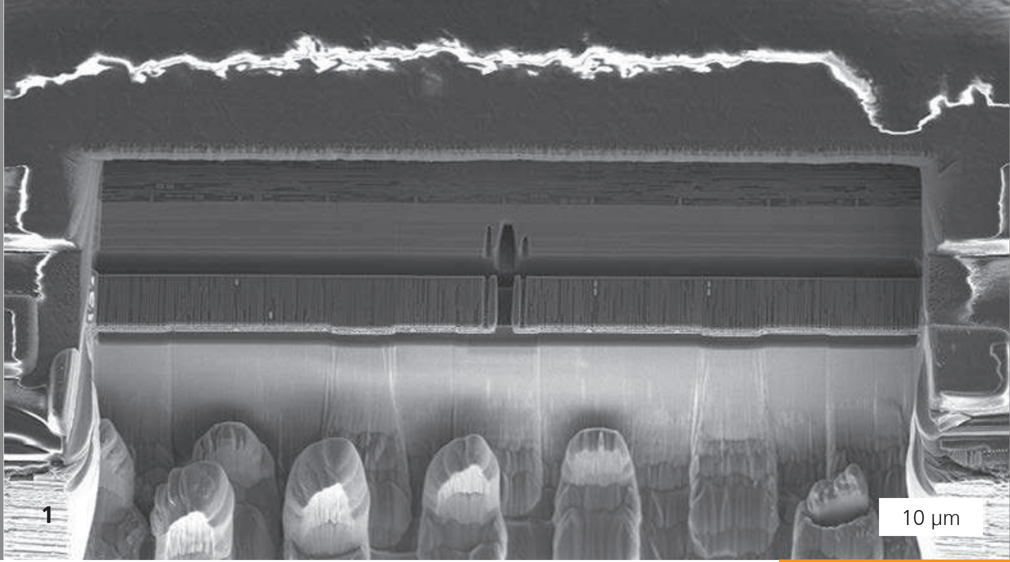

MULTISCALE MATERIALS DATABASE FOR 3D IC MICROELECTRONICS

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The microelectronics industry has been pursuing the strategy of shrinking technology nodes to increase the transistor density and efficiency for decades now. This trend has been governed by "Moore's law", which states that the costs per transistor are halved approximately every two years. However, this economic law has come up against its physical limits, forcing new approaches, such as "More than Moore", to be taken. These concepts entail further integration of microelectronics elements through 3D stacking of silicon-based dies (3D-integrated circuits, or "3D IC" for short), leading to thermomechanical stresses due to the thermal expansion mismatch between the integrated materials. To guarantee the reliability of a 3D IC, it is necessary to perform FEM simulations with precise materials properties (e.g., CTE, Young's modulus, and Poisson's ratio). Often, these materials properties cannot be determined with standard characterization techniques and thus new, advanced methods are needed. In addition, the scales of the 3D IC parts differ by several orders of magnitude, making FEM models of complete 3D ICs very complex. An alternative approach is the simplification of a 3D IC model using mean values for the materials properties for distinct parts of the 3D IC. These materials properties form a multiscale materials database.

One part of a 3D IC that can be simplified in an FEM model is the back end of line (BEOL), the on-chip wiring level, comprising a mesh of dielectrics and copper. The characterization of the mean values for CTE and Young's modulus requires specimen sample preparation using the focused ion beam (FIB) technique in the scanning electron microscope (SEM). Precisely defined regions of the BEOL are excavated in the form of free-standing cantilevers to allow investigation of the elongation under the influence of heat and the compliance under mechanical loading. In the characterization of the coefficient of thermal expansion, the elongation of the specimen on a hot stage is observed in the SEM at a high resolution and is analyzed using automated image analysis routines. For determination of the Young's modulus, the free-standing cantilevers are each loaded at the free end with a nanoindenter. During loading, the cantilevers bend and the loading forces and displacements are recorded with a high resolution.

With these two methods, anisotropic CTE and Young's modulus behavior can be investigated for various regions of the BEOL as a function of copper volume fraction and dominant copper line direction. Complex BEOL structures can be modeled with less detail using these effective materials properties, with mean materials properties replacing distinct BEOL building blocks. In FEM simulations of microelectronic devices at the chip package or transistor level, these BEOL simplifications enable analysis of larger models or a significant decrease in computing time with the same level of accuracy as that of detailed BEOL models.

1 *SEM image showing two free-standing cantilevers for the investigation of the coefficient of thermal expansion and the Young's modulus. The back end of line (BEOL) was excavated utilizing the focused ion beam (FIB) technique.*

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