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Collaborating components in mesh-based electronic packaging

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Abstract. From the model geometry creation to the model analysis, the stages in between such as mesh generation are the most manpower intensive phase in a mesh-based computational mechanics simulation process. On the other hand the model analysis is the most computing intensive phase. Advanced computational hardware and software have significantly reduced the computing time – and more importantly the trend is downward. With the kind of models envisaged coming, which are larger, more complex in geometry and modelling, and multiphysics, there is no clear trend that the manpower intensive phase is to decrease significantly in time – in the present way of operation it is more likely to increase with model complexity. In this paper we address this dilemma in collaborating components for models in electronic packaging application.

1. Introduction

Computational aided engineering (CAE) is a key element in the design and analysis of electronic packaging products, from conceptual design to manufacturing operations and processes. The geometric model, commonly known as a computer aided design (CAD) model, facilitates all the down stream phases in the CAE process for a product. With the product design and analysis occur early in the sequence of the process chain, their success is vital to all subsequent activities to eventual product fabrication and time to market. For models needing computational mechanics analysis such as heat transfer of an integrated circuit chip, a model for the geometry of the solid object (and may be also the surrounding domain) is needed. This is frequently performed by the CAD system with built in solid modelling functions. Next the assigning of material types and boundary patches before finite element mesh generation of the model domain, then the analysis may begin. For a fully integrated CAE process the stages between the geometric modelling to the start of analysis is generally straightforward, but this is not always true. Some non-trivial examples are listed. (1) A particular kind of meshes is needed such as structured mesh solvers, which are not so common when the geometry modeller forms part of the analysis software package. (2) CAD model not directly suitable for mesh generation such as those assembled components that are not merged ideally leaving holes and gaps. (3) Mesh generation difficulties, including sheer size and complexity of the model, demanding on computing resources. Any problems encountered between the two stages require man-time for attention and adjustment, and these activities become frequent and are extremely time-consuming. Some of the difficulties can be solved by more advanced technology in algorithmic, software and hardware, but the kind of models envisaged which are much larger, more complex in geometry and modelling, and multiphysics, the man-time is unlikely to decrease significantly. It is possible to assume the total modelling time being consist of geometry creation, meshing and analysis. The analysis part may have greatly reduced its computational time, due to advances in computational hardware, software and numerical techniques, and more importantly the trend

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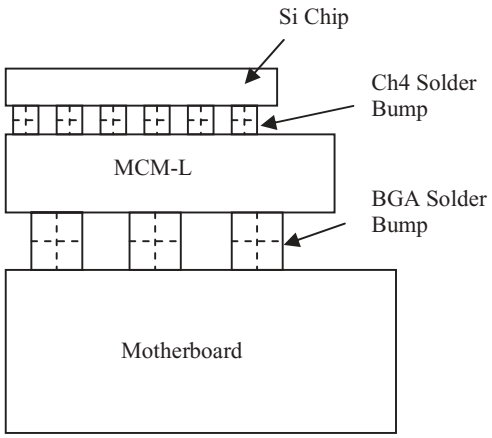

Fig. 1. A multiple chip geometry.

is downward. However the first two parts of the modelling time have not been reduced to the same level, because it is professional-manpower intensive, and with no clear downward trend. Therefore it is unlikely the total modelling time will decrease vastly in the present way of design operations.

The time to market in electronic packaging is decreasing rapidly, the product design and analysis cycle need to be shortened to meet the challenge, not just by reducing the number of design cycles but smart and more efficient ways of operations. In the sections below, the component meshing and gluing (CMG) approach is introduced for multi-chip module (MCM) problems in electronic packaging. This kind of problem is frequently makeup of basic shapes (blocks, cylinders, etc.) and when assembled together it becomes a complex geometry model to undertake; the relative scale between the components is a key factor. Figure 1 shows an example diagram of MCM geometry.

2. Component meshing and gluing concept

The component meshing and gluing (CMG) approach takes a more natural approach, in the same light as an engineer assembling components in CAD to construct the solid model. Here, the object model is a collection of assembled meshed components. Like CAD systems' database that uses a parametric approach defining the geometry component relative to parameters such as length and thickness, for rapid model creation. The CMG follows the same concept with the component volume meshed, and is perhaps most suited to applications where models are constructed from a few basic shapes such as multi-chip module (MCM) models in electronic packaging.

The model of assembled components is then "glue" together by either merging components to form one mesh model or collaborating components using some iterative methods. The former methodology requires the use of polyhedral type elements to combine into one mesh model, and it is referred to as the CMG-Coupled strategy in this paper. One disadvantage of the CMG-Coupled strategy is that it does not apply to all solvers, for example, structured mesh solvers. Only solvers with polyhedral element capability can be considered. The latter methodology requires some iterative methods to collaborate the components through the exchange of boundary conditions between the components' interface, and it is referred to as the CMG-DDM in rest of paper. The solution of each component may be obtained by means of existing fast solvers. This is more universally applicable to all types of solvers, but one known disadvantage is that the computing time to solution is longer. Fast iterative methods in domain decomposition (thus we called this strategy CMG-DDM) can significantly shorten the time to solution but it is unlikely to match the single mesh case. For appropriate solvers, a combination of the two gluing strategies is possible.

The new approach virtually removed the difficulties in the previous operation and speedup the model creation and meshing processes. The tools for model creation and meshing in the process-chain are very much for constructing components for the meshed-component database. And any assembled models can be added to the database as meshed-components for use in other models. The volume-meshing element is not figured in the assembled model construction process, thus removing a potential manpower intensive element from the procedure. The only meshing related element that perhaps needing manpower input is the component's interface, this is not envisage – because it is a surface-meshing type problem and is one degree of dimension less than volume meshing thus full automation is expected. The downside in CMG-DDM is the expected longer analysis time, but if this is not too excessive the reduction time gained in model assembly could well offset the extra computing time and achieve a reduced overall modelling time. This is the ultimate goal, but until then when the analysis time is too excessive, we do have the parallel computing armaments to address the longer analysis time – remember the trend for the analysis part is downward.

3. Numerical techniques

Provided that the solvers can take polyhedral elements, the CMG-Coupled strategy does not require extra effort to put into the solvers. It is the mesh-model that needs to be connected at the finite-element mesh topology level, gluing the interfaces of the mesh components. This is essentially a finite-element mesh connectivity problem. In the CMG-DDM strategy, the domain decomposition method (DDM) [1] is ideally suited for the assembled-component model, with the non-overlapping class the most appropriate. A non-overlapping approach allows flexibility in the mesh processing, the methods of numerical solution, the handling of different physics, and the adoption of numerical solvers in each of the model components. This choice also makes the defect equation technique as developed in [2] an ideal method for CMG-DDM. The algorithmic methodology for the CMG-DDM by the defect equation techniques is as:

Let $\mathbf{L}u = f$ be defined in the domain Ω and $u = g$ on $\partial\Omega$, where $\mathbf{L}$ may be a nonlinear operator that depends on u, and g is a known function. The domain Ω is partitioned into M non-overlapped sub-domains such that $\bigcup_{i=1}^{M} \Omega_i = \Omega$ and $\Omega_i \cap \Omega_j = \phi$, for $i \neq j$. Each sub-domain is associated with a sub-model defined by $\mathbf{L}_i u_i = f_i$. The boundary of each sub-domain, $\partial\Omega_i$, subtracting the part of boundary which overlaps with the boundary of the entire problem is in essence a part of the interface. Therefore the interface, which attached to Ω_i, may be defined as $\gamma_i = \partial\Omega_i \setminus \partial\Omega$. The boundary conditions defined on γ_i may be denoted by and it satisfies a defect equation, such as $D(u_\gamma) = 0$ [2]. Using superscripts to denote the number of gluing process, the CMG-DDM algorithm may be written as follows.

Initial value : $n = 0$; $u_i^{(0)}$ $i = 1, 2, \ldots M$ are given.

Repeat $\{n := n + 1$;

For $i = 1, \ldots M$ Do

$u_i^{(0)} := \{$Solve $\mathbf{L}_i u_i^{(n)} = f_i$ in Ω_i subject to

$u_i^{(n)} = g$ on $\partial\Omega \bigcap \partial\Omega_i$

and $u_i^{(n)}|_{\gamma_i} = u_{\gamma_i}\}$;

End-Do

Solve $D(u_\gamma) = 0;\}$

Until Convergence achieved

When the model consists of a single domain (meshed component) then the For loop and the defect calculation, $D(u_r) = 0$, are redundant, thereby reverting back to the conventional solution procedure. The CMG-Coupled cases are performed in this way. From the above algorithm the For loop may be run in parallel and on homogeneous computing systems the solution will be identical between parallel and scalar computations.

4. Numerical experiments

The particular problem to be considered in this paper is governed by the 2-D energy equation, limited to conduction only, in temperature u. The variables in (2) are density (ρ), specific heat (c), thermal conductivity (k), time (t) and the source term (S).

$$\rho c \frac{\partial u}{\partial t} = \nabla \bullet (k(\nabla u) + S(u) \tag{1}$$

The nonlinearity is introduced in the form of a material phase-change in the source term. For solidification using the enthalpy source-based method this is given by

$$S(u) = L\rho \frac{\partial f(u)}{\partial t} \tag{2}$$

where L is the latent heat and f is the liquid fraction. The algorithm for solving these kinds of problems may be found in papers by Chow and Cross [3] and Voller and Swaminathan [4] and is not discussed in this paper. Readers interested in obtaining more information are directed to these references. In this study, the numerical stable method of Voller and Prakash [5] solidification algorithm is used.

A nonlinear problem with phase-change occurring inside the domain, geometry as that of Fig. 1, was used to conduct our numerical experiments and investigations. Three experiments conducted were; 1) A steady state heat transfer (no phase-change) where the top surface is at a temperature of 10 C and bottom surface of 100 C. The left side of the model is symmetry and for all other boundaries, a convective heat boundary condition of ambient temperature of 25 C with a heat transfer coefficient of 10.0 W/m^{2}C. 2) A transient heat transfer problem that has the same boundary conditions as the first experiment with an initial temperature of 100 C. The time step size taken was 10 seconds interval and simulation time end at 120 seconds. 3) The final experiment is a heat transfer with the small solder bumps (Ch4 Solder Bump in Fig. 1) undergoing solidification. The boundary condition is essentially the same as the

Table 1
Geometry dimension of components in test model

	Length (mm)	Height (mm)	Gap interval (mm)
Si chip	10.5	1.5	
Ch4 Solder bump	1.0	1.0	1.0
MCM-L	15.5	2.0	
BGA solder bump	2.0	2.0	3.0
Motherboard	19.5	3.0	

Table 2
Material properties

	Density kg / m^3	Specific Heat J / kg C	Conductivity W / mm C	Liquidus temp. C	Solidus temp. C	Latent heat J / kg
Board	1400	838	0.18			
Solder	8400	171	50.6	183	180	3700

Table 3
Total energy in system and computing times (Computing Platform: Window 2000, 2GHz Pentium 4, 1 GB RAM)

	Conformal mesh		Non-conformal mesh	
	Coupled computation	Collaborating components	Coupled computation	Collaborating components
	Steady State Results (*obtained with residual L2-norm tolerance of 1.0e-6*)			
Total energy	8.998910166	8.998910109	8.998117691	8.998120956
Relative error		6.334100E-09	8.806344E-05	8.770062E-05
Computing time	0.031	2.234	0.015	2.015
Iteration number	2	230	2	232
	Transient Results (*obtained with residual L2-norm tolerance of 1.0e-6*)			
Total energy	9.378820792	9.378820836	9.384847314	9.384851563
Relative error		4.691421E-09	6.425671E-04	6.430202E-04
Computing time	0.172	7.640	0.156	6.906
Max. Iterations	2	75 (1st)	2	75 (1st)
Min. Iterations	2	61	2	59
	Solidification Results (*obtained with residual L2-norm tolerance of 1.0e-6*)			
Total energy	15.214174680	15.214174700	15.185239930	15.185216610
Relative error		1.314564E-09	1.901828E-03	1.903361E-03
Computing time	49.296	101.563	35.094	94.547
Max. Iterations	78 (1st)	79 (1st)	77 (1st)	78 (1st)
Min. Iterations	19	23	18	23

previous two experiments with both top and bottom surfaces now have the convective heat boundary conditions. The initial temperature is at 183 C with time step size of 2 seconds interval and simulation time end at 600 seconds.

Table 1 shows the dimension of the components in the experiment model, the material properties data used in the experiments are given in Table 2. In the experiments, only for convenient, the Si-Chip, MCM-L and motherboard takes on the material property of the Board dataset, and both the Ch4 and BGA solder bumps takes on the Solder dataset. For the third experiment, only the Ch4 solder bumps are solidifying, the liquidus and solidus temperatures for BGA solder bumps are set above that given thus no solidification occurs.

Figure 2 shows two different meshes used in present experiments. Figures 3 to 5 shows the cell invariant temperature distribution of the coupled computation and collaborating components for the three experiments. The plots are indistinguishable between the coupled computation and collaborating components. Where as the temperature profile on the two meshes (conformal and non-conformal) is virtually impossible to tell apart. Table 3 give the total energy in the system domain and computing costs for the simulation, together with iteration numbers required. The coupled conformal mesh result is used as the reference guide towards measuring accuracy and computing performance. In the transient problems, the iteration numbers shows the first time step has the highest iteration counts, this is obvious due to the cold starting the simulation, whereas lowest is found in time steps towards end of simulation. The coupled computation for linear problems, Experiment 1 and 2, require 2 iterations for both steady state and per time step in transient to achieve convergence on temperature. The largest devi-

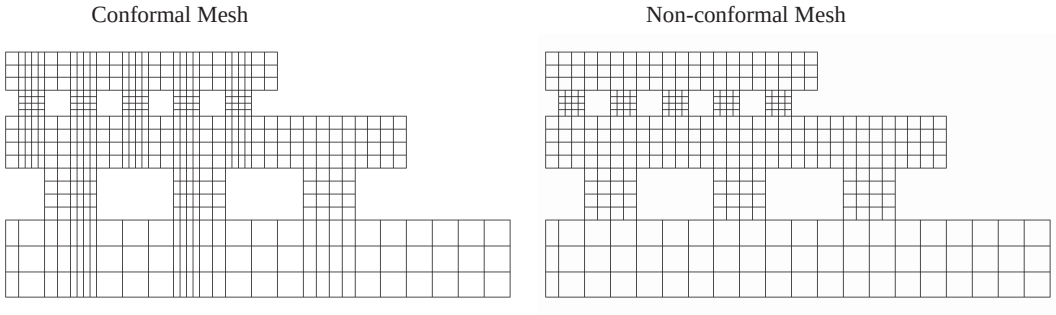

Fig. 2. Two different meshes used in experiments.

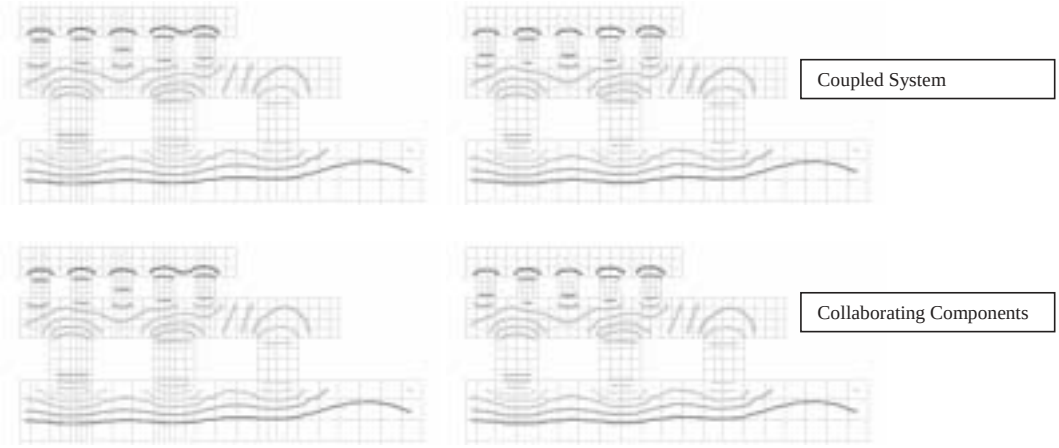

Fig. 3. Comparison of the temperature distribution of steady state results.

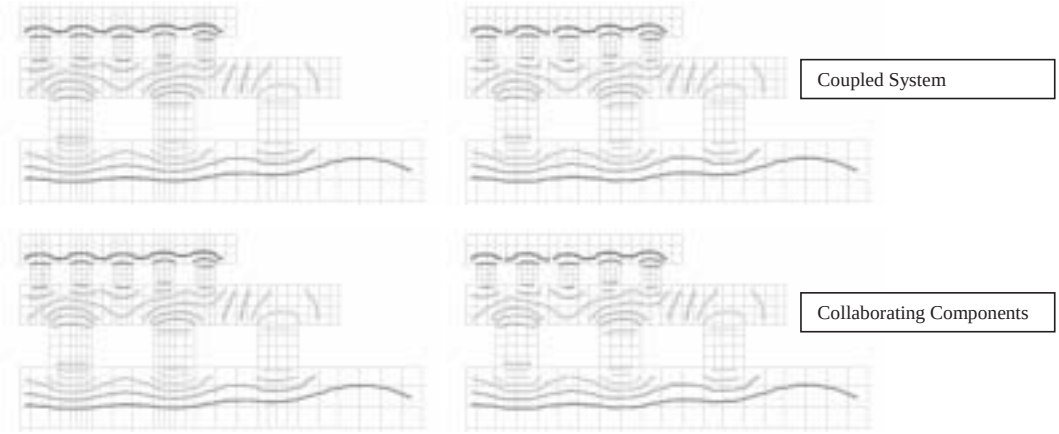

Fig. 4. Comparison of the temperature distribution of transient results.

ation of the solution from the referenced data is under 0.2% in Experiment 3, and under 0.07% and 0.01% respectively for Experiments 2 and 1. Computing times for collaborating components for the two meshes (conformal and non-conformal) are 72.1 and 65.0 in Experiment 1, 44.5 and 40.2 in Experiment 2, and 2.1 and 2.0 in Experiment 3, times more expensive respective to the referenced coupled conformal mesh cases.

Based on these results the collaborating component approach for linear problem is not competitive, but non-

linear problem is a different proposition. Assuming 25% of overall time is used for analysis, this implies the projected total modelling time of 197 for coupled computation in Experiment 3, which suggests there is possibility for the collaborating component approach to be competitive in non-linear phase-change problems in electronic packaging.

5. Summary

Numerical experiments of solder solidification based on the enthalpy method [3,4] for multiple chip module shows the potential advantage of the method in electronic packaging applications.

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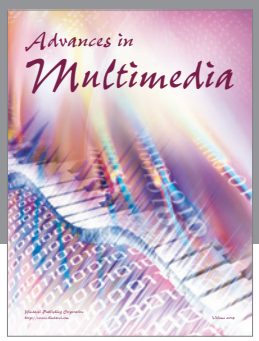

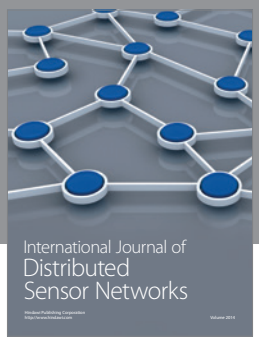

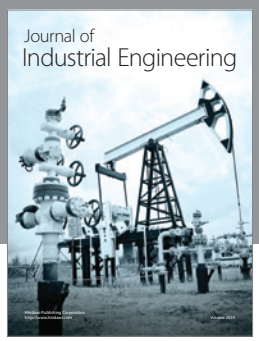

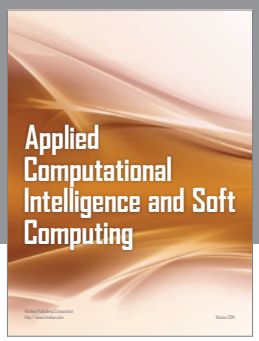

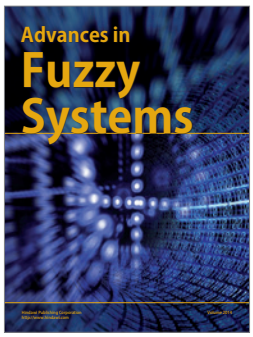

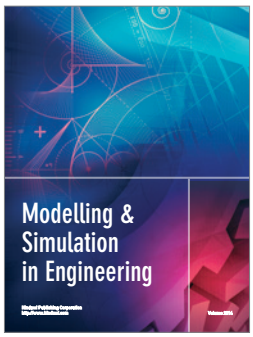

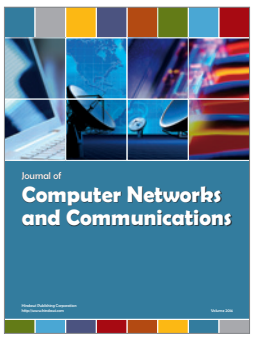

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