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Topology Optimization of a Composite Heat-Sink Involving a Phase-Change Material

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ABSTRACT

Many electronic devices require their operation temperatures below a Set Point Temperature (SPT) for efficient and reliable performance. Transient thermal management of electronics is being actively studied where heat-sinks operate for intermittent periods of time. In this context, a cooling concept called the composite heat sink (CHS) is being considered. Basically, CHS contains a phase change material (PCM) such as wax and a base material (BM) such as aluminum. The objective of the PCM is to keep the temperature of the electronic device below the SPT. Owing to the low conductivity of PCM, BM is used along with it to dissipate the heat. The design objective for this kind of cooling applications is to maximize the time of operation of the electronics while maintaining their operation temperature below the Set Point Temperature (SPT). Active research is being carried out to obtain such a design [1, 2] mostly using the sizing optimization of a common design which involves the base material (BM) fins protruding into a reservoir of phase change material [1].

In this context, our interest is to consider the feasibility of using topology optimization technique to conceive an optimal design of CHS encompassing a variety of possibilities that have not been considered before. In this work, we use Solid Isotropic Material with Penalty (SIMP) technique for continuous variation of topological distribution of paraffin wax and aluminum in a given design domain [3,4]. We model phase-change using the enthalpy method on a fixed grid [5]. This enables continuous modeling of the topology design space. The two materials are to be optimally distributed to maximize the time before the operation temperature of the electronic device reaches SPT. We performed gradient based optimization where the computation of gradients plays a major role. Analytical gradients are computed using a Discrete-Discrete [6] and a Continuous-discrete approach [7]. It is important to note that use of analytical gradients saves significant amount of time and also improves the reliability of the computed gradients; thereby making the optimization process feasible. We considered only heat transfer by conduction but the framework developed allows for including other heat transfer modes in the model.

Two approaches are developed to perform topology optimization: the first is to directly maximize the time of operation for an SPT and the second to optimize an alternative objective function evaluated for a fixed time. In the latter approach, various objective functions are considered to determine the best one, keeping in view, maximizing the time of operation. The merits and demerits of both the approaches are

studied and a comparative study of the various objective functions that come under the latter approach is performed. Practically important aspects in topology optimization such as the choice of initial guess and effect of penalization in SIMP design parameterization are studied. We performed optimization taking into account a composition constraint as well as the unconstrained case. The optimal solutions obtained in both the cases are compared and the role of the composition constraint in obtaining manufacturable designs is discussed. We studied the efficacy of MMA and Optimality Criteria although MMA is used to perform optimization in most of the cases.

We performed all the above mentioned studies on a sample problem which represents a worst case scenario. It has to be noted that the framework developed is general and allows for optimization in various situations. We also show that when a known intuitively conceived design is given as initial guess, the method is able to give a better design that has both intuitive and non-intuitive features. All computations are carried out in the integrated environment of Comsol with Matlab™ [8, 9] which is a finite element based partial differential equation solver.

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