

Models and Method for variation and uncertainty management in Micro-manufacturing during the design phase.

Background:

For the purpose of this study, the term micro-manufacturing refers to the creation of high-precision three dimensional (3D) products using a variety of materials and possessing features with sizes ranging from tens of micrometers to a few millimeters. While microscale technologies are well established in the semiconductor and microelectronics fields, the same cannot be said for manufacturing products involving complex 3D geometry and high accuracies in a range of non-silicon materials. At the same time, the trends in industrial and military products that demand miniaturization, design flexibility, reduced energy consumption, and high accuracy continue to accelerate -- especially in the medical, biotechnology, telecommunications, and energy fields. By and large, countries with traditional strengths in manufacturing have continued to invest heavily in recent years in micromanufacturing R&D for several reasons. First, the demand from the global market for ever-smaller parts and systems at reasonable cost and superior performance is strong. This demand tends to drive the high-end research. Second, the prospects of multidisciplinary research are causing companies increasingly to blend material science, biology, chemistry, physics, and engineering to speed up technology innovation and thereby new applications based on microtechnology.

The technologies used to design NLBMM (non-lithography-based meso- and microscale) parts and the processes and equipment used to fabricate them are in a nascent stage. These technologies have been, for the most part, borrowed from the design practices of macroscale engineering and very large-scale integration (VLSI). At present, most designers have difficulty ascertaining the appropriate time to use pre-existing design knowledge, theory and tools. Designers must be able to assess the suitability of pre-existing technology for the design of NLBMM parts. Otherwise, design processes will be long and iterative, with the result that the products' benefits will be either delayed or lost.

Fabrication processes are often scale dependent. For instance, traditional macroscale techniques such as milling are not generally applicable at the nanoscale. Likewise, the nanoscale processes used by nature to build biological systems are not generally applicable to the fabrication of some large-scale parts. The range of utility for a specific fabrication process generally terminates within the meso- or microscale. This is an important point for designers to realize; designers must "design for" compatibility of microscale parts with parts that were fabricated using a macro- or nanoscale fabrication processes. Microelectromechanical systems (MEMS) and very large scale integration (VLSI) designers encounter this issue in the form of packaging challenges.

The link between design and manufacturing has led to design for X (DFX) methods (Boothroyd et al., 1994) and concurrent design practices (Syan and Menon, 1994) that are used to help designers select appropriate design-fabrication process combinations. Although the general idea of DFX and concurrent engineering may be considered scale-independent (the design of parts to be made with fabrication processes that are cost and/or time appropriate), the implementation of these practices depends upon the fabrication processes that are to be used. The small-size scale of NLBMM parts makes it necessary to use new or adapted versions of existing manufacturing technology. As a result, new DFX rules will be needed to help designers make design-process choices that ensure scale-specific manufacturability and cross-scale compatibility.

Standards for NLBMM parts are currently in a nascent stage and require better definition. Of particular importance are the standards for measurement and evaluation of part characteristics.

Without these standards, designers will have difficulty talking with vendors, customers, and others about the specifications that drive the design and fabrication of their parts. These standards should cover geometry, material properties, optical properties, electromagnetic properties, and other related characteristics. Designers need to understand how to design NLBMM parts so that they are compatible with standard measurement methods. The existing techniques for measuring the characteristics of NLBMM parts are far from ideal. Many of these techniques are slow, provide only 2D information, and require destructive evaluation. Clearly, improved measurement tools are needed, as will be explained in a later chapter of this report. A set of rules that govern the design of NLBMM parts “for measurement” does not exist. As a result, most designers use intuition and advice from metrology vendors to design parts that may be measured in a way that does not affect the rate of manufacturing and does not lead to long time constants for manufacturing processes control. Metrology technology is traditionally slow to develop. As such, early designs must be compatible with available technology. “Design for Standard Measurement” will be important to the rapid adoption of NLBMM parts.

Scientific issue:

This proposal focuses on design for variation and uncertainty management of the micro-manufactured product and its micro-manufacturing process. At the most basic level, “design” is a process that is used to generate, evaluate and select a solution for a given problem. Uncertainty and risk are unavoidable when designing in the absence of full knowledge. Uncertainty stems from the lack of knowledge required to model performance. The risk that is associated with a particular design may be ascertained if one is able to use models to define a probability of success. In short, it is better to be in a position to ascertain risk than to be in a position of uncertainty. Throughout this assessment, little evidence has been found to suggest that stochastic methods have been employed during the design of NLBMM parts. Given the nascent state of the NLBMM technology, one finds variation in fabrication processes, metrology tools, material properties, and other aspects which must to be considered during the design process. The ability to model these variations and use such models to assess risk is important for two reasons:

Knowing the risks may help to prevent the stifling of design concepts in the face of erroneously perceived high risks.

A good understanding of risks may be used to guide the distribution of resources toward designs that have a higher probability of success.

The scientific main objective is to improve methods for variation and uncertainty management during this design phase. This proposal will focus on a contribution in developing:

Models to predict the quality of micro-manufactured part (Prediction of surface roughness and dimensional deviation). Prediction of surface finish and dimensional deviation is an essential prerequisite for developing a micro-manufacturing process. Two main attributes of job quality are surface roughness and dimensional deviation. Surface finish has a great influence on the reliable functioning of two mating parts. A reasonably good surface finish is desired for improving the tribological properties, fatigue strength, corrosion resistance, aesthetic appeal of the product, ... Excessively better surface finish may involve more cost of manufacturing.

Methods for risk assessment. There is a need for modeling and simulation tools that link the performance of components to variations in the characteristics of the part and the variations in the performance of a system to variations in the performance of its parts. In many cases, the preceding may be addressed by custom-made, stand-alone simulations (e.g., Monte Carlo simulations). Unfortunately, many of these tools are difficult to learn and they are not integrated with existing geometric and behavioral modeling tools. This is perhaps the reason that stochastic design tools are not widely used in engineering design.

Methods for parts tolerancing. Micro-manufacturing processes are characterized by high process variability and an increased significance of measurement uncertainty in relation to tight tolerance specifications. Therefore, it is important to take into account not only the micro manufacturing process capabilities but the measurement uncertainty.

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