MEMS Cleanroom Particle Contamination Flow Visualization Through Fluid-Structure Interaction Simulation

S. P. Regalla[1], S. R. Vutla[1], A. Shushanth[1], P. K. Pattnaik[1], K. Ramaswamy[1], M. B. Srinivas[1]

[1]Birla Institute of Technology and Science Pilani, Hyderabad Campus, Hyderabad, Telangana, India

Abstract

This paper reports the simulation micro-electro-mechanical system (MEMS) cleanroom for the purpose of determining the effect of particulate contaminants on the static stress response of cantilever type MEMS devices, such as high precision MEMS pressure sensor. The contaminant presence has been qualitatively verified through computational fluid dynamic simulation of the clean room in COMSOL Multiphysics environment and quantitatively estimated for adverse conditions such as ISO-8 cleanliness. The typical cross-section of cleanroom with machine tables, machines on them and operators has been approximated as a two-dimensional model. Initially the sharp edges of the tables and human models were retained but convergence problems were encountered in COMSOL. Then the sharp edges have been converted to rounded edges with certain radius after which convergence became possible.
INTRODUCTION: Microelectromechanical systems (MEMS) component manufacturing and product fabrication is done in a clean room at cleanliness levels ranging from ISO-7 to ISO-5 and this is critical to the successful operational performance of the product [1]. Particularly in applications involving smaller structures while scaling down from micro to nano electrical systems, the decoupling of mass and stiffness and the influence of surface contamination become important and thereby the sensitivity and response time of the electromechanical sensors are affected [2]. In addition to particulate density the other parameters that affect the product quality are room pressure, temperature and relative humidity and all these parameters need to be maintained within very narrow tolerances. Specially built rooms, air flow systems, air filters and air handling units coupled with water chillers are required to maintain these tolerances. Not only that little standardization exists for these parameters for MEMS products but also most of the experimental MEMS clean rooms in India are still in their infancy. Whenever these parameters are not maintained within the required tolerances, we call the clean room condition as "adverse clean room environment". Such adverse conditions can lead to particle and contaminant depositions on the component surfaces, non-uniform thermal distortions and condensation of moisture at critical and unreachable portions of the MEMS device, and in turn leading to its erroneous performance.
USE OF COMSOL MULTIPHYSICS: The problem of finding the air flow pattern in the cleanroom was simulated in COMSOL Multiphysics environment using fluid-structure interaction module. It was solved as stationary problem. Actual dimensions of the cleanroom constructed at the authors' Institute and the machinery therein were used in the simulation. The actual values of

cleanroom parameters, namely the number of fan filter units in the ceiling, vents in the floor and flow velocity at the top have been supplied as input. The two-dimensional finite element analysis took about 30 minutes to converge on a typical Core-i5 laptop.
RESULTS: Fig-1 shows the Multiphysics modeling and Figure 2 shows the mesh. Note the mesh refinement at the corners of the tables and human models. Figure 3 shows the flow distribution. The arrow plot of the flow indicates that the flow along with the particle contaminants can reach the top of the MEMS component thus contaminating it. This qualitative information is very useful for undertaking a more detailed estimation model for predicting quantitative contaminant particle concentration and distribution pattern on the surface of the MEMS device. Based on this evidence and using an approximate methodology the amount of particles accumulating over the period of time and their distribution pattern on the surface of the MEMS device were determined. It was found that the distribution pattern in general can be Gaussian and also may be approximated as a uniformly distributed load. These two cases of loads were applied on the MEMS cantilever beam and the deflections of the MEMS cantilever beam were determined in COMSOL Multiphysics using its solid mechanics and MEMS modules. Figure 4 shows the Von-Mises stress distribution in the MEMS cantilever beam in one of the numerical experiments.
CONCLUSION: COMSOL Multiphysics software and its fluid-structure interaction module have been successfully used to obtain a qualitative estimate of flow pattern in a cleanroom. It gave an idea and qualitative estimate of extent of contaminant particle that can reach along with the flow of air and deposit on the MEMS component surface.

Reference

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Figures used in the abstract

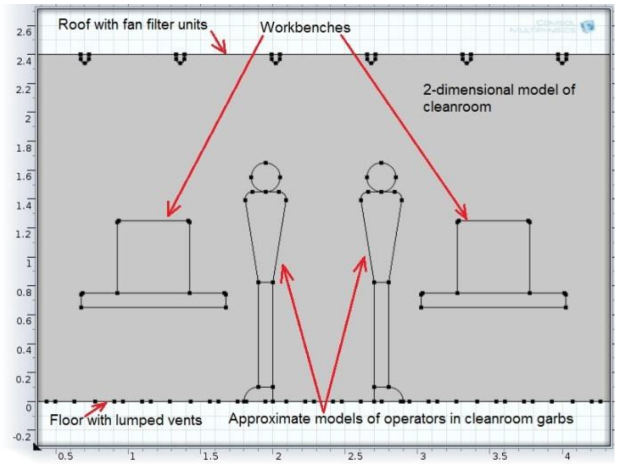

Figure 1

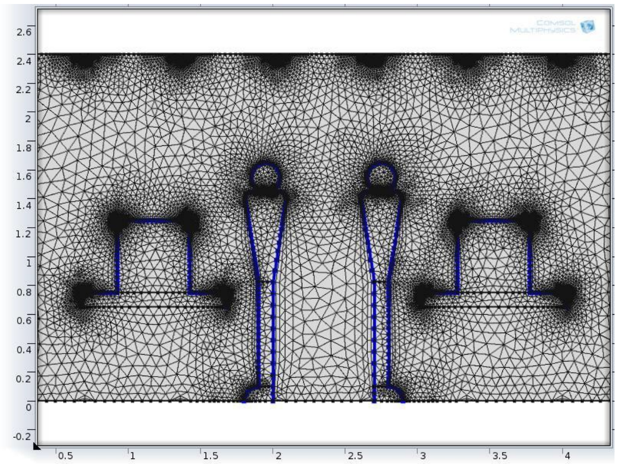

Figure 2

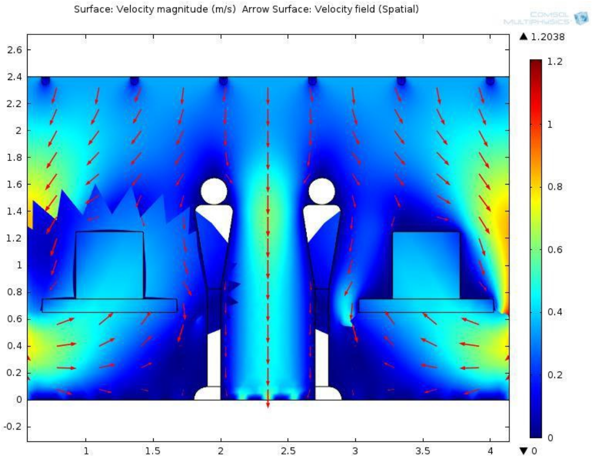

Figure 3

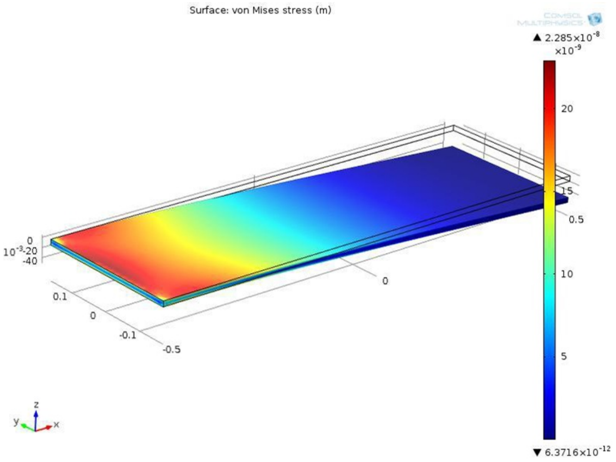

Figure 4