Including reliability in the design of optical micro electro mechanical systems

Shanti Bhattacharya

By building it in from the start, higher long-term device yields are possible.

OMEMS (optical micro-electro-mechanical systems) are devices that use light either explicitly, as in the well-known digital micro-mirror device found in projectors, or implicitly, as in a sensor that consists of light coupled into a fiber. In the latter case, the extent of coupling can be related to a change in a parameter such as temperature or pressure. In either case however, communicating with an OMEMS device presents challenges that are not faced with a purely electrical MEMS device, because it can be completely sealed off and accessed through metal contact pins. Ensuring a hermetic seal with a glass window or input fibers is more difficult. Therefore, in a design process context, two important questions need to be addressed. First, given the special requirements of an OMEMS device, where does one begin a design process that takes all constraints into account? Second, some applications require that these devices work without failure for periods as long as 20 years. How can their reliability be improved?

Reliability engineers study how systems age due to repeated use over time. Typically, they ask questions like: how does the behavior of a mirror change if it is switched a billion times? How does reduced hermeticity affect mirror reflectivity or how does a temperature change affect fiber position? The main task is usually to provide information on when a device will stop working and for what reason.

However, our claim is that reliability information should be included in the design, so that a device can still meet specifications even if some parameter was subsequently changed. However, this is only possible for a certain amount of change. This is why including reliability in the design process means extending the maximum range of error allowed for a given parameter. The importance of developing a design process has been discussed elsewhere, but without, considering reliability data. As for reports that do discuss reliability, they do not explicitly discuss OMEMS nor the concept of maximum range.

Let us consider an optical design process. Since many specifications must be met, only one is selected as the key design

Figure 1. Complete design flowchart.

Continued on next page
parameter. For example, insertion loss (IL) could be that parameter. This means that all other parameters are varied to optimize this specification. The design process begins by collecting all the relevant information such as wavelength, mode field diameter, etc. and by listing all the design constraints, such as maximum mirror tilt, dimensions of the optical components, etc. Using Gaussian equations, parameters such as focal length and distances between elements can be calculated, after which IL and MEMS parameters can be determined. At this stage, a check is made to ensure that all parameters are realistically achievable by the manufacturers and the intended MEMS process.

Once a realistic design is available, the sensitivity of the device to each parameter is calculated. This is achieved by varying each parameter individually within its error range and monitoring its effect on IL. In this way, a maximum range is assigned for each error affecting the system, such that the overall IL remains within specifications. Alternately, the range may be set by manufacturer specifications. For example, the optical design may require a 1mm-focal length lens. The manufacturer may specify his lenses as having focal lengths with values of $1 \pm 0.01\text{mm}$. The error range for focal length is then 0.02mm. In a real system, errors will occur simultaneously. Therefore, in order to calculate IL for the entire system, a Monte Carlo analysis is carried out by randomly picking a value for each parameter from anywhere within its specified range.

So far, reliability for time-varying changes are not yet included in the process. Although they need to be taken into account, there is no consideration of how or why a change has occurred, but only of the maximum range through which the relevant parameter can vary. Since this approach is the same as that used in standard optical design, including optical reliability issues in the design process is then straightforward, once reliability experiments have provided relevant data. A flowchart of such a design process is shown in Figure 1.

The problem that we set out to solve was two-fold. We needed a systematic design approach that could also include reliability data so as to improve the long-term functioning of the device. We have developed a design method that incorporates the known quantities of the design along with calculated error ranges. Our calculations show that including reliability error ranges can improve the long term yield. The method requires further testing involving more designs using actual reliability data.

The author gratefully acknowledges partial support for this work from the Micromachined Product Division of Analog Devices Inc.

Author Information

Shanti Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology
Chennai, Tamilnadu, India
http://www.ee.iitm.ac.in/~shanti/
http://www.ee.iitm.ac.in/

Shanti Bhattacharya obtained her PhD in physics in 1997. She then worked in Germany as a Humboldt fellow in the field of diffractive optics. Following this, she worked in the area of OMEMS at Analog Devices Inc, USA. She is currently an assistant professor in the department of Electrical Engineering at the Indian Institute of Technology in Chennai, India. Her current research interests are fiber interferometry, diffractive optical elements and OMEMS.

References