Avoiding Low Cycle Fatigue in Solder Material of IC Packages
Ephraim Suhir
Portland State University, Portland, Oregon, and ERS Co., USA, e-mail address: suhire@aol.com

Abstract
Three practically important problems associated with the reliability of solder joint interconnections (SJI) in IC packages are addressed:
1) Could inelastic strains in the solder material be avoided by a rational physical design, and if not, could the sizes of the inelastic strain areas be predicted and minimized? SJIs are the most vulnerable structural elements in the today’s IC packages: the solder material often experiences inelastic strains, and, because of that, suffers from low cycle fatigue conditions, and its fatigue lifetime is often shorter than required for many applications. There is an obvious incentive therefore to explore ways to bring down the induced stresses and strains in this material, even, if possible, to an extent that the inelastic strains are avoided. If this is impossible, the size of the inelastic zones could be, desirably, predicted and minimized.

2) The difference between an highly reliable and an insufficiently reliable IC product is “merely” in the level of their never-zero probability of failure. Since SJIs are usually the most vulnerable structural elements in an IC package design, could this probability be assessed at the design stage and, if possible, made adequate for the given application? The recently suggested probabilistic design-for-reliability (PDFR) concept enables assessing the probability of the operational failure by using predictive analytical (“mathematical”) modeling that determines this probability from the highly focused, highly cost-effective, carefully designed and thoroughly conducted, when developing a new manufacturing technology, failure-oriented-accelerated testing (FOAT). Highly physically meaningful and flexible multi-parametric Boltzmann-Arrhenius-Zhurkov (BAZ) equation, developed about a decade ago, could be applied to predict this probability from the FOAT data. The BAZ equation is based on the Boltzmann’s equation in classical thermodynamics, Arrhenius equation in physical chemistry and Zhurkov’s equation in experimental fracture mechanics.

3) Should temperature cycling accelerated testing for SJIs be replaced with a more physically meaningful, less costly, less time- and labor- consuming and, most importantly, less misleading test vehicle? Temperature cycling, the most widespread accelerated test today, is costly, time- and labor consuming, and, most importantly, can result in misleading information. This is mostly because electronic materials’ properties are temperature dependent, and testing is done in a temperature range, which is, as a rule, much wider than what the material will most likely encounter in actual operation. Since the highest thermal stresses occur in SJIs at low temperature conditions and, as is known from fracture mechanics, fatigue crack propagation is effectively accelerated by random vibrations, a low-temperature/random-vibrations bias is suggested as an attractive substitute for temperature cycling, especially for applications, when such a bias reflects the actual loading conditions. The general concepts are illustrated by detailed numerical examples.

Reference
E. Suhir, Avoiding Inelastic Strains in Solder Joint Interconnections of IC Devices, CRC Press, Boca Raton, Florida, 2021

Bio: Ephraim Suhir is on the faculty of the Portland State University, Portland, OR, USA. He is also CEO of a Small Business Innovative Research (SBIR) ERS Co. in Los Altos, CA, USA, is Foreign Full Member (Academician) of the National Academy of Engineering, Ukraine (he was born in that country); Life Fellow of the Institute of Electrical and Electronics Engineers (IEEE), the American
Society of Mechanical Engineers (ASME), the Society of Optical Engineers (SPIE), and the International Microelectronics and Packaging Society (IMAPS); Fellow of the American Physical Society (APS), the Institute of Physics (IoP), UK, and the Society of Plastics Engineers (SPE); and Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA). Ephraim has authored about 500 publications (patents, technical papers, book chapters, books), presented numerous keynote and invited talks worldwide, and received many professional awards, including 1996 Bell Laboratories Distinguished Member of Technical Staff (DMTS) Award (for developing effective methods for predicting the reliability of complex structures used in AT&T and Lucent Technologies products), and 2004 ASME Worcester Read Warner Medal (for outstanding contributions to the permanent literature of engineering and laying the foundation of a new discipline “Structural Analysis of Electronic Systems”). Ephraim is the third “Russian American”, after S. Timoshenko and I. Sikorsky, who received this prestigious award. His most recent awards are 2019 IEEE Electronic Packaging Society (EPS) Field award for seminal contributions to mechanical reliability engineering and modeling of electronic and photonic packages and systems and 2019 Int. Microelectronic Packaging Society’s (IMAPS) Lifetime Achievement award for making exceptional, visible, and sustained impact on the microelectronics packaging industry and technology.