

# **Celebrating Fifty Years of Physics of Failure**

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# Prelude

## **PoF related events prior to 1950:**

- A. Wohler summarized fatigue test results on rail-road axles (1870).
- Basquin proposed log-log relationship for stress-life curves using Wohler's fatigue test data (1910).
- Griffith introduced his theory of fracture (1921).
- Epstein published the statistical foundation for assessment of the life of materials subject to fracture (1948).

## **PoF related events in the period between 1950 and 1962:**

- US DOD formed the Advisory Group on the Reliability of Electronic Equipment (AGREE) (1952).
- Several conferences began to focus on various reliability topics (e.g., 1955 Holm Conference on Electrical Contacts) (1950s).
- The Rome Air Development Center (RADC) introduced a PoF program to address the growing complexity of military equipment and the consequent higher number of failures observed (1961).

# Birth of Physics of Failure

The first PoF symposium in electronics was jointly organized in Chicago by the RADC and IIT Armour Research Foundation (1962).

- This symposium laid the groundwork for future research and development activities related to PoF by RADC and several other organizations.
- Numerous original papers and ideas introducing and explaining the PoF concepts and methods were presented in this first symposium:
  - PoF should seek to relate the fundamental physical and chemical behavior of materials (i.e., failure mechanisms) to reliability parameters (Vaccaro, 1962).
  - PoF is based on the principle that to eliminate the occurrence of failures, it is essential to eliminate their root causes, and to do that one must understand the physics of the underlying failure mechanisms involved (Vaccaro, 1962).
  - There is need for identifying probable failure mechanisms by which components fail as a function of time, environmental and operating stresses (Davis, 1962).

# **Symposium on PoF in Electronics (1963 – 1966)**

The PoF symposium continued to be held after that presenting a wide range of PoF concepts and methods:

- PoF analysis is an essential step in planning accelerated tests as well as evaluating them (Bretts et al., 1963).
- Different causes of failure of a component include failure due to accidental damage during manufacture, assembly, testing, storage, or failure in service due to operating conditions or failure of another component (Church and Roberts, 1965).
- Nondestructive inspection and screening procedures based on PoF which later formed the basis for prognosis and health management concepts (Gill and Workman, 1966; Potter and Sawyer, 1966).

# IEEE IRPS (1967 –)

IEEE sponsored the Reliability Physics Symposium (IRPS) from 1967 onwards that continues today to present a wide range of PoF related research:

- Hollingshead introduced a technique for optimizing the selection of parts for system application by reliability and quality levels through systematizing the compilation and processing of necessary data (Hollingshead, 1970).
- A model for predicting electromigration time to failure (Black, 1974).
- A model for time dependent dielectric breakdown of semiconductors as a function of operational and environmental conditions and the device's physical parameters (Crook, 1979).
- A methodology to monitor and predict early life reliability failure mechanisms (Conrad et al., 1988).

# Other PoF Related Researches

By the late 1980s and early 1990s, several publications on PoF related research outside of the IEEE IRPS also appeared:

- The use of PoF approach for reliability assessment as opposed to the part count technique was advocated (Pecht et al., 1990).
- A series of tutorial papers to review important material failure mechanisms and damage models were published (Dasgupta and Pecht, 1991).
- Failure models for mechanical wear modes and mechanisms were presented (Engel, 1993).
- Empirically-based reliability prediction approaches (e.g., MIL-HDBK-217) were compared with the PoF approach, and several limitations of the MIL-HDBK-217 were identified that could be addressed using the PoF approach (Cushing et al., 1993).

# Probabilistic PoF

Several publications on probabilistic consideration of PoF also emerged from the early 1990s:

- Probabilistic PoF (PPoF) is a technique in which the statistical lifetime model is derived considering the PoF (Mendel, 1996).
- A PPoF approach to reliability assurance of high-performance chips considering common defect activation energy distribution (Haggag et al., 2000).
- PPoF models for component reliabilities by considering parameter and model uncertainties (Hall and Strutt, 2003).
- A Bayesian framework for physics-based reliability models (Azarkhail and Modarres, 2007).



# Other Important Milestones

- A Physics-of-Failure based handbook of microelectronic systems was published (Salemi et al., 2008).
  - The handbook was the first of its kind to present an approach for microelectronic system reliability assessment and qualification based on PoF in a sum-of-rate approach to account for multiple mechanisms.
- Another important activity currently underway is the development of a Web Accessible Repository of Physics-Based Models (WARP) under the aegis of the Reliability Information Analysis Center (RIAC).
  - The objective of the WARP is to collect and analyze the characteristics of the PoF models for electronic, electromechanical and mechanical components in order to provide a centralized web-based repository accessible to researchers and engineers.

# Summary

- RADC deserves special recognition, including its chief and founder Joseph J. Naresky, under whose leadership PoF was first formally conceptualized in the symposium on “Physics of Failure in Electronics” organized in 1962, with considerable efforts also by RADC’s Joseph Vaccaro.
- Many of the original ideas introduced in these symposia continue to have a significant impact on today’s understanding of failures in electronics and have offered enduring models for estimating life characteristics.
- The PoF approach encompasses multiple disciplines, such as reliability engineering, physics, metallurgy, mathematical statistics and probability.
- While PoF analysis is complex and costly to apply, it provides the strongest characterization available of reliability of components, structures and systems.
- As an approach for reliable product development, PoF has gained wide acceptance today in the commercial sector (e.g., at Microsoft) as well as in several countries (e.g., Japan, Singapore, and Taiwan)—a tribute to its strong foundation established fifty years ago.