Empirical modeling in the area of technological process optimization and optimization of the burn-in process of electronic devices

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Abstract: - Monitor the microelectronics structures stability, consistency and overall performance need to study variation and influence of various technological factors. This article presents some important aspects related to the observation and analysis of the influence more than one variable at a time on the response of interest. Examples for creating maps of performance stability for supposed device operating conditions and related experience of realized studies are recapitulated here.

Key-Words: - multi-vari analysis, variation, optimization, experiment, factor, response, design

1 Problem introduction, important aspects of burn-in process of electronic devices

In our research we need to study multiple sources of variation related to the modification of microelectronics structures, technological process factor settings and burn-in process.

Burn-in is the process of exercising of electronic devices to accelerated test. This is the process of operating devices under accelerated voltage, temperature, or load in order to screen out infant mortality failures. The understanding of the burn-in procedure is very important question related to planning and controlling of burn-in process in production of electronic devices. In practice, the underlying mechanisms of the burn-in process are frequently so complicated that an empirical approach is necessary.

The traditional probabilistic approach is to a large degree replaced by empirical study approaches constructed on designed reliability testing experiments. The methodological approach is based on manipulation of factors (independent variables) in order to determine the effect of this manipulation on other response variables (dependent variables).

2 Some aspects of causality evaluation and basic terms

Experimental methods are used in research and development as well as in industrial settings for various purposes: determination of the effect(s) on some behaviour (the dependent variable) while controlling other relevant factors, examination of a hypothesized causal relationship between independent and dependent variables, observation of the effect of the treatments on the experimental units by measuring one or more response variables, translation of the different research hypotheses into a set of treatment conditions, reach "cause and effect" conclusions about the effect, evaluation of the statistical significance of an effect that a particular factor exerts on the dependent variable of interest, observation whether cause and effect relationships are present, settings of the technological factors in order to make the output that meet certain quality requirements.

Discovering key relationships between inputs and outputs is for quality control and improvement very important. Tools such as Cause and Effect diagram (also known as a “Ishikawa Diagram” or “Fishbone”), Cause and Effect Matrix, correlation analysis or Design of Experiments give advice in discovering causal relationships.

Fig.1: Graphical illustration of process variables and process output variables. Independent variables describe
input parameters and dependent variables describe the output variables.

An experiment is a study in which the investigator manipulates one or more variable to determine its effect on the response variable(s). The former variables are call “independent variables”; or “factors”; the latter are call “dependent variables” or “dependent measures”. Graphical illustration of this type of problem is at the Figure 1. Input factors or factors within a process correlated to an output parameter(s) important to the customer are Key Process Input Variables. Key process input variables for processes must be understand in order to manage them in order to achieve given quality and reliability goals. Critical to Quality characteristic(s) related to output of a process that are important to the customer are sometimes call Key Process Output Variables (KPOV). Critical to quality characteristics are typically categorize under Quality or Reliability, Time, and Cost. These characteristics of product or service are usually determined from a qualitative (external or internal) customer statement and then translated into quantitative specification. The appropriate specification can allow comparison of actual result of KPOV against target or specification.

2 Observation and analysis of more than one variable at a time

The traditional technique to experimentation is based on changing only one factor at a time whilst holding the remaining factors constant. This method however doesn’t provide data on interactions of factors and it isn’t cost effective. There is no way to account for the effect of joint variation of factors and it usually isn’t possible to hold all other variables constant and a large number of runs are required.

The overall combination of all factors and their levels can grow to be too large and daunting a task if each factor is changed one at a time. An alternative approach called factorial design can uncover interactions and is more efficient than the approach of one factor at a time approach. The statistical design of experiments enables to plan an experiment that simultaneously alters a number of experimental variables to evaluate how they affect response parameters. The factorial design that varies multiple factors at a time can reduce the number of runs and still offer enough information. Factorial Designs are form of DOE where one or more trials are making with each combination of levels for the factors. This approach provides the way to the analysis of the effects of multiply technological factors on the response.

One of the strengths of the factorial experiment is that it allows the study of several factors at once, rather than only one factor at a time. DOE, in contrast to the one factor method, advocates the changing of many factors simultaneously in a systematic way. A response surface is a surface that represents predicted responses to variations in factors in the region of interest. The region of interest is the set of runs, in which combinations of vital continuous factor levels are included, that are perform in order to predict investigated response. A mathematical statement of the relations among variables can be express as an empirical model. The most common empirical models fit to the experimental data take polynomial form.

3 Response surface description and response surface methodology

Response surface methodology helps to quantify the relationships between one or more measured responses and the vital continuous factors. The response is a dependent variable of interest in an experiment whose changes we wish to study. It is a characteristic of an experimental unit measured after treatment and analyzed to address the objectives of the experiment. In most experimental situations, several responses are usually of interest, and their selection is related to the purpose of the study. In the context of industrial experiment are the responses related to the quality characteristics of a product which are most critical to customers.

Identifying quantifiable responses is very important steps of an experiment execution. Responses must be measured by capable measurement system that consistently produces reliable results.

Attribute data (pass/fail, good/bad) are for design of experiment purposes inefficient. These data ask for a large number of experimental units and leads to experimental plans that are time and resources consuming. One way to solve it is to define the numerical rating scale (e.g. 1-very bad to 3-okay to 7-very good) by providing benchmarks in the form of defective units or pictures and train about three people to use the scale. To evaluate the response, each trained people should independently rate each experimental unit after the experimental treatment. Then the response should be the average rating for each experimental unit, but it can be also evaluate the standard deviation of the ratings as a second response.

Response Surface Methodology approximates the response values $Y$ in the form of polynomial function of independent variables $x_i$, $x_j$: The symbol $n$ is the number of independent variables and $a_{0}, a_{i}, a_{ii}, a_{ij}$ are model coefficients.
Response surface methodology is used to determine the optimum combination of factors setting that yield a desired response and describe the response near the optimum or to determine how a specific response is affected by changes in the level of the factors over the specified levels of interest. The eventual objective of RSM is to gain understanding of the physical mechanism of a system.

4 Study of the microelectronic structure in the relation to the study of burn-in process influence

In this part is presented the example presents the simultaneous study of the effects that three vital continuous factors (concretely temperature, time and voltage) have on the microelectronic structure (concretely electrical parameters stability coefficient), see Figure 2.

<table>
<thead>
<tr>
<th>FACTOR</th>
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<tbody>
<tr>
<td>A</td>
<td>High</td>
<td>B</td>
<td>High</td>
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<tr>
<td>B</td>
<td>Center</td>
<td>C</td>
<td>Low</td>
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Fig.2: Experimental factors and their levels in the study of the influence of the burn-in process

Factors can be divided into control and noise factors. Control factors are those factors that can be deliberately manipulated during the experiment; these are during experiment changed across the experimental plan from run to run. Noise (lurking, nuisance) factors are background variables that are difficult, inconvenient or too expensive to control in actual experimental situation. Noise factors include time, day, ambient temperature, humidity, air flow or test conditions.

Unfortunately these uncontrolled variables can be a major cause for variability in the responses. The effect of background variables can contaminate primary variable effects unless they are properly handled by randomization, replication and blocking.

Determination of the important control factors that can affect the responses and selection levels or settings for each of these factors during the experiment can be done by various ways. Cause and effect diagram, flowcharts, brainstorming or brain writing are useful tools for this.

At various treatments are control factor setting at various levels. The levels need to be in an operational range of the product or process. The number of levels depends on the experimental factors, nature of the experimental design and whether or not the selected factor is variable or attribute. The cost of experimentation can grow significantly if too many factors and/or levels of factors are selected. If important factors are left out of the experiment, then the results may be inadequate.

The experimental plan for the presented example is depicted in the Figure 3. This can be used for study the effects of three experimental factors in 15 runs. According the experimental plan each factor was varied at high (+), central point (0) and low (-) levels according the experimental design as sum up in Figure 2. Center points serve to test for the presence of curvature, and give information about quadratic effects.

There is a simple underlying geometric structure to all factorial experimentation. For presented example, a three-factor experiment can be represent as a cube in which each corner represents one trial, see Figure 4.

From the fitted regression model was create the response plot. The response plot shows a plot of the effects for two of the factors on the response. Example of the response plot is in the Figure 5.

Experimental factors are generally explanatory variables that might influence the response variable. These are the possible causes of variation that affect the response. Factors may be variable (continuous - thickness, pressure, voltage) or they may be attribute (discrete, categorical - production method, type of material).
Fig. 5. Estimated response surface for tantalum capacitor structure stability evaluation

5 Conclusion

One of the most important problems in industrial research is the discovery of the optimum conditions of technological process. In some cases it is possible to calculate the optimum conditions on theoretical grounds, much more often, however, only an empirical approach is possible.

It is unwise to design too comprehensive an experiment at the start of a study. The idea of using information from the early parts of a series of observations to design the later work is termed the sequential approach to the discovery of the optimum conditions of technological process.

This paper describes some aspects of experimental cause and effect evaluation and presents some results of burn-in process sequential experimental evaluation. The used methodology consists of appropriate experimental plan that yields the most information from predetermined model with the least number of experiment runs. Empirical model coefficients and approximate models in the reference points obtained from the experimental data are created based on a multivariate regression analysis of each investigated response. When the region of experimentation is a long way from the top of the optimum a slope may be a good approximation. This approach can be used for characterization, qualification, and testing in relation to quality improvement and statistical process analysis purposes.

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