Research on Data Processing Method for Reference Materials Preparation

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Abstract This paper focuses on the data processing method for reference materials preparation. By analyzing the data of reference materials (RMs), the process of repeatability and stability verification, uncertainty estimation, traceability of the value of a quantity and the characterization of RMs are detailed in the paper.
Keywords Reference materials, Data processing, Repeatability and Stability verification, Uncertainty estimation

I. Introduction

Microelectronic reference materials called as RMs for short, is a special circuit as a standard of dissemination, of which one or several parameters are certified. RMs has three notable characters. Firstly, it is for measurement. Secondly, it has the accurate certified values. Lastly, its value could be traced to the source.

RMs has been applied in many fields. The main function is that they present the contrasts of the dissemination of the value of a quantity. On the same hand, RMs have the following two purposes. One is that RMs will act as golden devices for the dissemination of the value of a quantity between similar sorts of devices. The other is that they can verify the testing equipments and disseminates the value of a quantity to them. Recently, the preparation and measuring abilities of RMs are becoming the key techniques of microelectronic metrology.

Instead of self-manufacturing chips, a popular preparation technique is to select matured samples as the RMs. By using the technique, the quality of the RMs depends mainly on the certified value of their characteristic parameters. Thus, the data processing control of RMs becomes more and more important.

This paper focuses on the data processing method for reference materials preparation. The process of repeatability and stability verification, uncertainty estimation, the traceability of the value of a quantity and characterization of reference materials are detailed in the paper according to data analysis.

The organization of this paper is as follows. Section 2 introduces the preparation processes of RMs. The data processing method for RMs preparation are discussed in Section 3. Finally, Section 4 concludes this paper.

II. Preparation Process of CMs

Since microelectronic devices are delicate and hard to design and produce, the costs of self manufacturing are too high and couldn't assure the stability and reliability as well. Therefore it is reasonable to select samples from matured products as RMs. RMs can be used for equipment verification and have huge benefits such as randomicity and wide-range for selection. The preparation process for RMs can be divided into the following 10 items[1].

- Confirmation of raw and processed materials.
- Temporary marks.
- Purchasing.
- Test at three different temperatures.
- Burn-in (Static and Dynamic).
- Leak detection.
- Final test at normal temperature.
- Determination of valuated parameters.
- Value assignment (contrast of triple sides).

- Naming and packaging (marking).

III. Data processing method for RMs preparation

The data processing is performed under the following conditions. The measure equipment for RMs is Agilent 93000. Independent test results x_i for i=1,2,…,n, are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. The reproducibility condition is where test results y_j for j=1,2,…,m, are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment at different times. The relationship between them can be described by Equation (1,2).

$$y=\{y_1,\ y_2\ldots y_m\} \quad (m\geq 4) \tag{1}$$

$$y_j=\{x_1,\ x_2\ldots x_n\} \quad (n\geq 6) \tag{2}$$

where

i is repeatability test time,

j is reproducibility test time.

A. Outlier test

Due to the accidental deviation of experiment conditions and methods or the error occurs in observation, records or calculation, there might be some members of a set of values that are inconsistent with the other members of that set. They are called outliers. Outliers cannot always be avoided and they have to be taken into consideration in a similar way to the treatment of missing data. The outlier test has a precondition that the original data are normal. Accordingly, a normality test needs to be taken before outlier test.

A.1 Normality test

Shapiro-Wilk's test has been chosen, for experience shows that the original data always present low kurtosis. Given a set of data x_i for i=1,2,…,n, arranged in ascending order, then to determine whether the set is normality using Shapiro-Wilk's test[2], compute the Shapiro-Wilk's statistic, W.

$$W=\frac{\{\sum_{i=1}^{[n/2]}\alpha_{in}[x_{(n-i+1)}-x_{(i)}]\}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{3}$$

where

$$\bar{x}=\frac{1}{n}\sum_{i=1}^{n}x_i \tag{4}$$

and

α_{in} is given in Shapiro-Wilk's coefficient table[2].

If the test statistic is less than or equal to 5% of its critical value, the item tested is accepted as correct, else the set should be rejected.

A.2 Outlier test

Since the number of the outliers is uncertain, Dixon's test, a two-sided outlier test, has been chosen for the sets which are normal. Given a set of data x_n for i=1,2,…,n, arranged in ascending order, then a Dixon's test is used to determine whether there's an outlier in the set[3], compute the Dxion's statistics, D_n、D'_n.

$$D_n=r_{11}=\frac{x_{(n)}-x_{(n-1)}}{x_{(n)}-x_{(2)}} \tag{5}$$

$$D'_n=r'_{11}=\frac{x_{(2)}-x_{(1)}}{x_{(n-1)}-x_{(1)}} \tag{6}$$

If the test statistics are both within 5% of its critical value, the set is accepted without outliers, else there is an outlier in the set.

B. Repeatability verification

B.1. Uncertainty estimation

a) Uncertainty (u_1) introduced by indication error

The uncertainty introduced by indication error is relative to the repeatability of data. Given a set of data x_i for i=1,2,…,n, (n≥6), u_1 is calculated in type A evaluation of uncertainty with Bessel's formula.

$$u_1 = \frac{s(x)}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{7}$$

where

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{8}$$

b) Uncertainty (u_2) introduced by the accuracy of driver

Assume the statistical distributing of data is uniform, the type B standard uncertainty u_2 is calculated as follows. Δ_1 represents the maximum permissible errors of driver.

$$u_2 = \frac{\Delta_1}{\sqrt{3}} \tag{9}$$

c) Uncertainty (u_3) introduced by the resolution of driver

The type B standard uncertainty u_3 is calculated assuming the statistical distribution of data is uniform. Δ_2 stands for the resolution of driver.

$$u_3 = \frac{\Delta_2}{2\sqrt{3}} \tag{10}$$

d) Uncertainty (u_4) introduced by measurement accuracy

In the case of a uniform distribution, the type B standard uncertainty u_4 is calculated while Δ_3 is the measurement accuracy.

$$u_4 = \frac{\Delta_3}{\sqrt{3}} \tag{11}$$

e) Uncertainty (u_5) introduced by measurement resolution

Δ_4 represents the measurement resolution, calculate the type B standard uncertainty u_5.

$$u_5 = \frac{\Delta_4}{2\sqrt{3}} \tag{12}$$

f) Combined standard uncertainty

The combined standard uncertainty, u_c, is calculated as the five above componets of uncertainty are irrelative.

$$u_c = \sqrt{u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2} \tag{13}$$

Calculate the degree of freedom, v_{eff}.

$$v_{eff} = \frac{u_c^4}{\sum_{i=1}^{5}\frac{c_i^4 u_i^4}{v_i}} \tag{14}$$

where

v_i is degree of freedom for u_i,

c_i is sensitivity factor.

g) Expand uncertainty U

Expand uncertainty is calculated as follows, taking v_{eff} into account.

$$U_p(\gamma) = k_p u_c(\gamma) \tag{15}$$

where

k_p is given in *t*-distributing table[3] while p is 0.95.

B.2 Repeatability verification

The sets without any outlier could be tested by repeatability verification. Given a set of data x_n for i=1,2,…,n, then calculate its experimental standard deviation, $s(x_i)$.

$$s(x_i) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{16}$$

If $s(x_i)$ is less than $\frac{2\sqrt{n}}{3}u_c$, the item tested is accepted as correct, else the set should be rejected.

C. **Stability verification**

C.1 Trend analysis of data

The first step in stability verification is to check whether there is notable trend of change of data. The model is

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{17}$$

where

β_0 and β_1 are coefficients;

ε is random error;

X is the time when reproducibility results are obtained,

Y is the arithmetic average of repeatability sets.

and

$$Y=\{X_1, X_2,\ldots X_m\} \quad (m\geq 4) \tag{18}$$

$$Y=\{Y_1, Y_2,\ldots Y_m\} \quad (m\geq 4) \tag{19}$$

$$Y_j = \bar{y}_j = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{20}$$

and

i is repeatability test time,

j is reproducibility test time.

The estimate of β_1 and β_0 , b_1 and b_2 are calculated as

$$b_1 = \frac{\sum_{i=1}^{m}(X_i - \overline{X})(Y_i - \overline{Y})}{\sum_{i=1}^{n}(X_i - \overline{X})^2} \tag{21}$$

$$b_0 = \overline{Y} - b_1\overline{X} \tag{22}$$

where

$$\overline{Y} = \frac{1}{m}\sum_{j=1}^{m} Y_j \ , \tag{23}$$

$$\overline{X} = \frac{1}{m}\sum_{j=1}^{m} X_j \; . \tag{24}$$

The standard deviation of b_1 is calculated according to the following formula.

$$s(b_1) = \frac{s}{\sqrt{\sum_{i=1}^{m}(X_i - \overline{X})^2}} \tag{25}$$

where

$$s^2 = \frac{\sum_{i=1}^{m}(Y_i - b_0 - b_1 X_i)^2}{m-2} \tag{26}$$

If absolute value of b_1 is less than the product of $s(b_1)$ and t-factor[3] while detection level is 0.05 and degrees of freedom relatively is m-2, there is no notable trend of data.

C.2 stability verfication

Given a set of data Y_j for j=1,2,…,m, calculate its experimental standard deviation, s_m.

$$s_m = \sqrt{\frac{1}{m-1}\sum_{j=1}^{m}(Y_j - \overline{Y})^2} \tag{27}$$

If s_m is not more than combined standard uncertainty u_c, the sets are accepted as correct.
The data are processed on Matlab platform. The result of characterization is in the form of certified value and its uncertainty, $y_a \pm U_a$.

D. Certified value validated

The result of characterization needs to be validated. In general, the distributing comparison method is used for validation. RMs are measured by the same grade of IC test system, getting the result as $y_b \pm U_b$. If $|y_a - y_b| \le (U_a{}^2 + U_b{}^2)^{1/2}$, the result of characterization is considered to be correct.

IV. Conclusions

Preparation of microelectronic RMs is still a challenging project in China because of the special characteristics of microelectronics, as well as the rigorous, time-consumed and complicated processes for traditional RMs preparation. And the data processing method is the key technique of RMs preparation. This paper presents a data processing technique for RMs preparation. In addition, the processing method could also be used in experimental proficiency testing, repeatability test as well as stability test. The process is a little complicated but could ensure the value of a quantity of RMs in our microelectronic measurement to be accurate and consistent.

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