



**Call for Improved Ultra-Low Background Alpha-Particle Emission
Metrology for the Semiconductor Industry**

**International SEMATECH
Technology Transfer #01054118A-XFR**

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Abstract: This paper is intended to help the semiconductor industry develop and communicate a consensus position for suppliers for improved, ultra low alpha-particle emission metrology equipment. The statement of need includes technical appendixes on the critical detection limit, targeted energy range and sample area.

Keywords: Critical Dimension, Metrology Equipment, Particle Detection, Soft Error Rate, Suppliers

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Table of Contents

| | | |
|------------|--|---|
| 1 | EXECUTIVE SUMMARY..... | 1 |
| 2 | SOFT ERROR RATE (SER) DESCRIPTION | 1 |
| 3 | THREE RECOGNIZED CAUSES..... | 1 |
| 4 | SEMICONDUCTOR INDUSTRY NEED..... | 1 |
| 5 | MEMBER CONSENSUS OF THE REQUIREMENTS FOR ULTRA-LOW ALPHA DETECTION EQUIPMENT..... | 2 |
| APPENDIX A | ALPHA-PARTICLE COUNTING CRITICAL DETECTION LIMIT | 3 |
| APPENDIX B | ADDITIONAL COMMENTS ON ENERGY RANGE..... | 5 |
| APPENDIX C | ADDITIONAL CONCERNS AND INTERFERENCES..... | 6 |
| C.1 | Comment on Detection Limit | 6 |
| C.2 | Comment on Sample Area | 6 |

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1 EXECUTIVE SUMMARY

This paper has been developed to help the semiconductor industry, as represented by the International SEMATECH member companies, develop and communicate a consensus position on an important need for the semiconductor industry to develop ultra-low alpha particle detection equipment. The recognized causes are defined and key attributes of the needed equipment are presented.

It is hoped that industry suppliers in particular will benefit from the assessment and definitions contained in this publication.

2 SOFT ERROR RATE (SER) DESCRIPTION

As the dimensions and operating voltages of semiconductor devices are reduced to satisfy the ever-increasing demand for higher density and lower power, their sensitivity to radiation increases dramatically. Radiation can induce localized ionization events capable of upsetting internal data states. While the upset causes a data error, the circuit itself is undamaged; thus this type of event is called a “soft” error and the rate at which these events occur is called the soft error rate (SER).

3 THREE RECOGNIZED CAUSES

It has been established that the SER observed in semiconductor devices is caused by three different types of radiation. The one type which this document is concerned is alpha particle emission from the thorium and uranium impurities (and their daughter products) in the device fabrication materials. With low operating voltages and ever-shrinking node capacitance, semiconductor devices are extremely sensitive to alpha particles. To enable acceptable SER performance, the semiconductor fabrication materials must be extremely pure to ensure that emission of alpha particles from the thorium and uranium (and daughters) is minimized.

4 SEMICONDUCTOR INDUSTRY NEED

There is an increasing urgency in the semiconductor industry to be able to monitor and measure the alpha particle emissions OR to be able to quantify the amount of radioactive impurities (all species) in today's materials. Current technology allows detection of an alpha emissivity of between 0.001–0.0005 alphas/hr-cm² and takes about 2 weeks (sample + background) to characterize. A new generation of equipment needs to be developed.

5 MEMBER CONSENSUS OF THE REQUIREMENTS FOR ULTRA-LOW ALPHA DETECTION EQUIPMENT

The International SEMATECH Soft Error Rate Team has developed a set of equipment measurement and cost metrics that are needed for ultra-low alpha detection. These metrics are presented here to encourage and facilitate instrument makers or interested parties to produce the tool needed. This is not a request for quotation.

Requirements are ranked in order of importance (from most important to least):

1. System should approach (as defined in Appendix A) a
DETECTION LIMIT ≥ 0.0001 alphas/hr-cm²
from 1 to 10 MeV (Appendix B)
2. Sample Area: 1500 cm² or less
3. Run Time (single run): Less than 1 week
4. Complete System Cost: Less than \$50,000 (US)
5. Additional Comments in Appendix C

Supporting statistics and reasoning are shown in Appendix A through Appendix C.

Appendix A Alpha-Particle Counting Critical Detection Limit

The following derivation is used to make a mathematical connection between the required critical detection limit of 0.0001 alphas/cm²/hr at 90% confidence, and the general parameters of the alpha-particle counting method. This application of statistics is based on Sections 2.18–2.20 of Tsoulfanidis¹. One assumption is necessary to apply this method: the background count rate measured in the absence of any sample is fully present during any measurements that include a sample. Thus, the presence of a sample cannot affect the background count rate of the measurement system.

Consider,

B = background counts

t_B = background count time

G = gross counts (sample+background) (i.e. a sample measurement)

t_G = gross count time

resulting in,

$N = G - B$ = net counts (sample only)

$n = \frac{G}{t_G} - \frac{B}{t_B}$ = net count rate

$\sigma_n = \sqrt{\frac{G}{t_G^2} + \frac{B}{t_B^2}}$ = standard deviation of net count rate

Consider the measurement of a sample that emits no alphas, $n = 0$, (zero alpha emission)

$$\frac{G}{t_G} = \frac{B}{t_B} \Rightarrow G = \frac{B}{t_B} t_G$$

Substituting into σ_n we get,

$$\sigma_{n=0} = \sigma_0 = \sqrt{\frac{1}{t_G^2} \left(\frac{B}{t_B} t_G \right)^2 + \frac{B}{t_B^2}} = \sqrt{\frac{B}{t_B^2}} \sqrt{\frac{t_B}{t_G} + 1}$$

The critical detection limit (*CDL*) can now be defined as,

$$CDL = \kappa_\alpha \sigma_0$$

where, κ_α = number of σ from $n = 0$ to the edge of α fraction area in the tail of a Gaussian distribution of possible n values (see Figure A1). Requiring a 90% confidence *CDL* means $(1 - \alpha) = 0.90$, yielding,

$$\kappa_\alpha = 1.28$$

¹ Nicholas Tsoulfanidis, *Measurement and Detection of Radiation, 2nd ed.*, Taylor & Francis, Washington, DC, 1995.

Finally, consider the measurement of a sample where: γ = sample alpha emissivity (alpha/cm²/hr), β = detector efficiency (fraction), and A = sample area (cm²). The net count rate is given by,

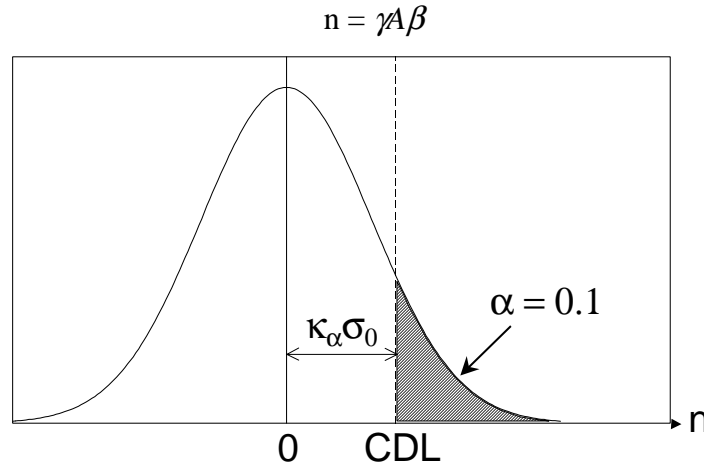


Figure A1

In order to distinguish this net count rate from the background we require,

$$CDL \leq \gamma A \beta \Rightarrow \frac{\kappa_\alpha \sigma_0}{A \beta} \leq \gamma$$

Substituting into σ_0 we get the general condition relating the required values, κ_α and γ , to the system measurement variable parameters: B , t_B , t_G , A , and β ,

$$\frac{\kappa_\alpha}{A \beta} \sqrt{\frac{B}{t_B^2}} \sqrt{t_B + 1} \leq \gamma$$

For the specific case of 0.0001 alpha/cm²/hr CDL at 90% confidence,

$$(1.28) \frac{\kappa_\alpha}{A \beta} \sqrt{\frac{B}{t_B^2}} \sqrt{t_B + 1} \leq 0.0001 \text{ [alpha/cm}^2\text{/hr]}$$

The following three statements help clarify the meaning of critical detection limit for a system with $CDL = \gamma A \beta$ at 90% confidence:

- a. 90% of all repeated t_G hour measurements of a zero alpha emission sample will result in a net count rate of $\gamma A \beta$ or less.
- b. A single t_G hour measurement of an unknown sample that yields a net count rate greater than $\gamma A \beta$ has a less than 10% chance of being the result of a zero alpha emission sample.
- c. If more than 10% of all repeated t_G hour measurements of an unknown sample yield a net count rate greater than $\gamma A \beta$, then the sample is not a zero alpha emission sample (i.e. the gross rate is greater than the background rate).

Appendix B

Additional Comments on Energy Range

In an ideal system the alpha flux would be measured along with its energy distribution. Depending on the method this capability may or may not be possible. As stated in the target requirements, the energy range of interest is 1 to 10 MeV (energies above 10 MeV can be allowed). In general it is advisable to discard events below 1 MeV in terms of noise margin since at these lower energies other background radiation events become much more significant. If a system comes close to but does not exactly meet the energy range specification it will still be considered.

If possible it would be very useful to build in the system the capability of have adjustable discrimination so that specific energy ranges could be set by the user. Furthermore, it would be extremely useful if the energy of each detection event could be determined so that a spectrum could be built up – obviously the plausibility of this feature depends on counting statistics and the method used for detection.

Appendix C

Additional Concerns and Interferences

C.1 Comment on Detection Limit

The method is not limited to direct alpha particle detection. Any technique can be employed, however the system must offer excellent run-to-run repeatability and needs to provide the capability of measuring alpha emissivities approaching 0.0001 alphas/hr-cm². It is important to note that this is a desired detection limit. If a system comes close to but does not exactly meet 0.0001 alphas/hr-cm² it will still be considered. The current alpha detection limit is ~ 0.001 to 0.0005 alphas/hr-cm².

C.2 Comment on Sample Area

If the system uses whole wafers (surface area techniques), the system should limit itself to four 150 mm or 200 mm wafers. Although more than this might be tolerated if the system meets the other criteria, this is a desired limit. Also, thought should be given to the fact that in the semiconductor industry the standard substrate for materials will be thin films on circular silicon wafers, thus, any geometrical advantages/disadvantage in the system layout should be considered. The detector area/shape should minimize the amount of non-sample area exposed. A circular system is probably non-ideal since besides circular wafer samples, there is a need to test rectangular/square samples. Obviously if the technique is based on material volume (such as chemical nuclear spectroscopic techniques) this is not a concern.

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