Alpha Emission of Fully Processed Silicon Wafers

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ABSTRACT

Measured alpha particle emissions from packaging materials have been used to calculate the Soft Error Rate of silicon components. The packaging materials have been assumed to be the only alpha emitter and the layers on top of the silicon have been assumed to be the alpha attenuators. This paper measures the alpha emission of the fully processed wafers from different vendors and shows that these wafers are significant alpha emitters. Because the alpha emitters in this case are very close to the silicon, there are no shielding layers to attenuate the lower energy alpha particle. The entire alpha particle energy spectrum, from both package materials to the inside wafers, must be considered , when calculating the alpha flux at the silicon die.

INTRODUCTION

SER has remained as a reliability challenge for IC chips as Si technology scales. The key contributors to the SER are: (a) high energy neutrons originating from cosmic rays in the natural environment; (b) alpha particles originating from trace radioactive material contamination in the IC package or wafer fab process; and (c) thermal neutrons originating from B10 in the BPSG layer used during the IC fab process [1]. Since the B10 can be controlled, the remaining contributors to SER are the high energy neutrons and the alpha particles. Recent work has shown that the alpha particle SER is higher than neutrons SER at the smaller geometries [2].

Since the alpha particle has a short range, a few tens of microns in packaging materials and less in metals and oxides [3], the semiconductor industry has focused on reducing the alpha emission of the packaging material near the die surface. For wire bond devices, the molding compound is the only material near the surface. The wire bond itself is also near the surface, but there usually aren't any SER sensitive circuits within 20 um of the bond. For flip chip devices, there are several packaging materials that end up close to the die, the underfill, bump, and presolder [4].

In order the reduce the number of alpha particles, which can penetrate into the die from the packaging materials, some semiconductor manufacturers have added attenuation layers on top of the die. These materials can be extra metal layers or polyimide [5].

The purpose of this work was to determine alpha emission of the fully processed wafer and determine if it is a significant source of alpha particles. Often the alpha emission rate of wafer is omitted with respect to the measurement and soft error rate calculation.

MEASUREMENT PROCEDURE

Conventional gas proportional alpha particle counters work by counting any electrical pulse that is generated after an alpha particle interacts with the counting gas. Free electrons created in the interaction pass through a region with a high electric field which creates gain and produces a large, clear signal. When measuring samples with very low alpha activity, the alpha emissions from the counter itself becomes significant. In this scenario, the sample activity is calculated as the difference of the total counts observed with a sample in the counter and an estimate of the counters background.

XIA's UltraLo-1800 alpha particle counter works as an ionization chamber, and is designed to distinguish between alpha particles emitted from the sample and those emitted from other parts of the counter by using pulse shape analysis. Operating without a gain mechanism, signal shapes produced by the counter are characteristic of where the alpha emission occurred; short fast pulses arise from ceiling emissions, and long slow pulses from sample emissions. A guard electrode is used to veto alpha particles that are emitted by the sidewalls. This discrimination technique assumes the sample covers the entire sample tray (1800cm^2), and cannot distinguish between alphas emitted from the sample and alphas emitted from exposed regions of the sample tray. In this case, a subtraction technique can be used to account for alphas emitted from exposed areas of the sample tray [6,7].

For this work, a custom circular electrode 300mm in diameter was developed and used to retrofit an UltraLo-1800 counter at XIA. The new electrode reduces the 'active area' of the sample tray and allows for direct measurement of 300mm wafers, while measurements of 200mm wafers also benefit due to the reduction of exposed tray area that must be subtracted.

Gas proportional counters typically set a discriminator around 2 MeV, which allows the gas proportional counter to eliminate unwanted beta particle pulses. This lower limit is justified since low energy alpha particles, emitted from the packaging material, will be attenuated by the layers of metal and dielectrics above the silicon. XIA's alpha counter is insensitive to beta particles and doesn't require a low energy discriminator, so measured emissivites could be slightly higher than those reported on proportional counters due to the additional counts of alphas which register below 1-2 MeV.

However, for our purpose, the alpha particles are being emitted from the layers on or in the silicon. Depending on where the alpha particle was emitted, the layers of metal could have attenuated the energy of the alpha particle. This alpha particle may have had enough energy to reach the silicon and should be counted in the alpha flux. Therefore, XIA's counter was chosen for this work.

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Samples were set in an Argon purged chamber, which can be mated directly to the counter, preventing air and Radon from entering the counter when the sample is inserted. This step eliminates the typical need to discard the initial hours of the measurement while Radon and its daughters decay away.

RESULTS

Figure 1 shows the calculated emissivity of the sample during the counting time. The calculated emissivity does not have the high initial counts usually observed. This allowed for faster measurements.

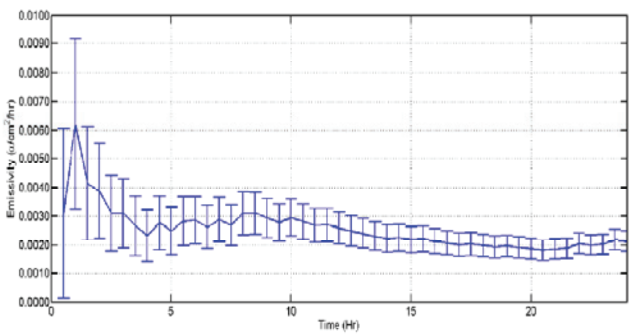

Figure 1. Calculated Emissivity during the counting time.

The alpha emission of wafers from several different fabs and technologies were measured. The silicon technology was labeled by the IRTS technology node and not the actual technology. Half nodes, or shrinks, are labeled as based technology node. The measured wafer alpha emissions are shown in Figure 2. Two bare wafers were measured and two wafer labeled "b" are with Ultra Low Alpha solder bumps on the wafers. The remaining wafers are processed wafer with the standard process flow out of fab.

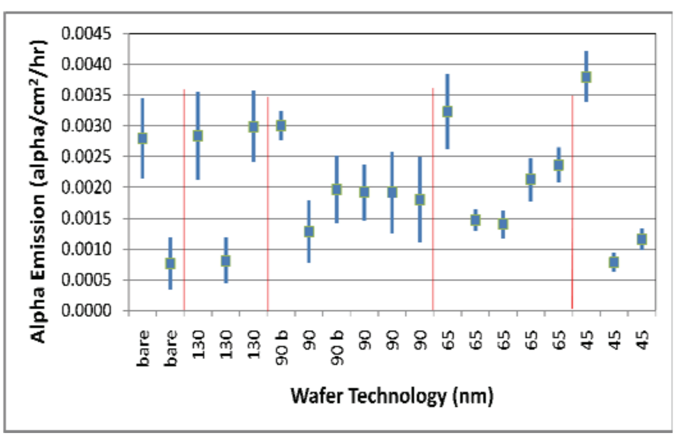

Figure 2. Wafer alpha emission by technology with 3 sigma error

The square is the calculated alpha emission and the error bars are the calculated 3 sigma errors.

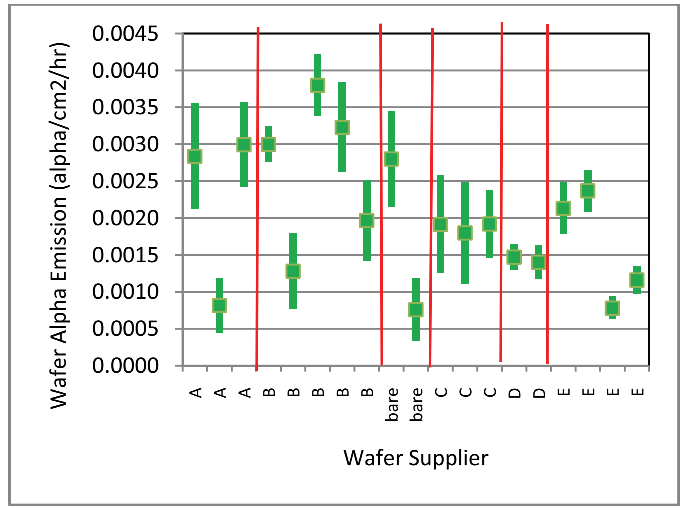

Figure 3. Wafer alpha emission by wafer supplier with 3 sigma error

Figure 2 and 3 shows no significant trend in the wafer alpha emission by wafer technology and wafer supplier.

Table 1. Alpha emissions of packaging materials

Alpha Emission Category	Alpha Emission ($a/cm^2/hr$)	Measured Alpha ($a/cm^2/hr$)
Uncontrolled/ Standard	10-0.01	NA
Low Alpha	<0.01	NA
Ultra Low Alpha	<0.001	0.00096 ± 0.00014

Packaging material above the wafer is categorized into the categories listed. One sample of Ultra Low Alpha molding compound was also measured. The sample met the 0.001 $alpha/cm^2/hr$ ULA requirement. This emission rate is lower than 16 of the 19 wafers tested.

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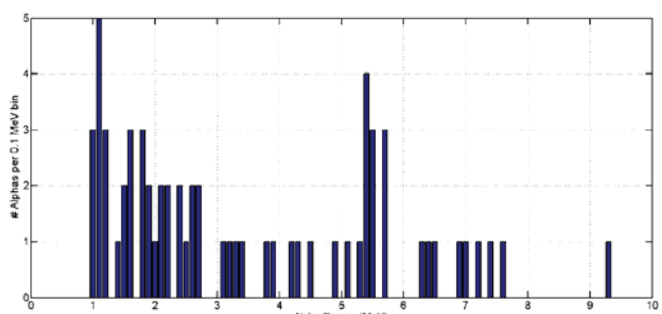

Figure 4. Alpha particle energy from a 90nm wafer, no solder bumps

Since the reflowed solder bumps on a wafer may affect the distribution of alpha emitters in the solder, the energy spectrum of a 90nm wafer with and without solder bumps was also measured. See Figure 4 and 5. The solder bumps did not produce any significant change in the alpha energy spectrums.

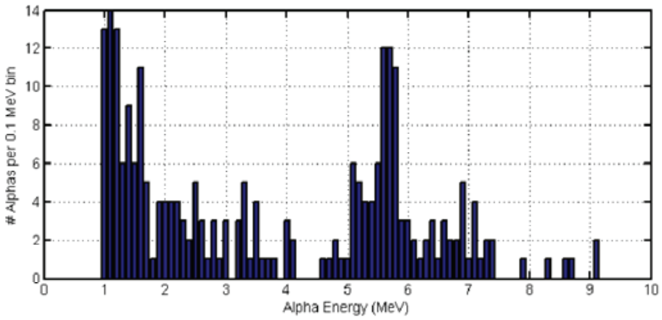

Figure 4. Energy spectrum of the alpha particle emitted from a 90nm wafer with solder bumps.

DISCUSSION

The fully processed wafer alpha emission varies from 0.001 to 0.004 alphas/cm^2/hr and does not show a technology or a wafer supplier trend. The Ultra Low Alpha packaging material emit alpha particles below 0.001 alphas/cm^2/hr.

In the past, with uncontrolled or Low Alpha emission packaging materials, the wafer alpha emission was insignificant. However, the fully processed wafers are emitting alpha particles at a rate similar to or higher than the ULA packaging material. The alpha emission of the fully processed wafers must be taken into account when calculating the alpha SER rate.

Process techniques to attenuate the alpha particles from the packaging materials such as adding thick polyimide or thick metal usually assume that the alpha emission of the shielding material is significantly less than the packaging material. This material is assumed to attenuate more alpha particles than it generates. This data shows that materials on the wafer may be contributing alpha flux than it is attenuating when Ultra Low Alpha packing material is used.

The addition of ULA solder bumps onto the wafers did not significantly change the energy spectrum of the alpha particle nor did it significantly change the overall wafer alpha emission. Therefore, ULA solder did not significantly change the wafer alpha emission even though it increased the surface area

To determine the alpha emissions of fab materials, individual layers of these materials could be deposited onto a wafer for alpha counting. These layers would have to be thick enough to block any alpha particle emitted from the underlying wafer so that the alpha particle counts would be from the specific material only. Materials such as copper could be a several microns thick. But materials such as ultra low K would have to be much thicker. This could be a challenge to since the ultra low K may not be mechanically stable in thick layers. A layered structure may have to be used, where the alpha emission of the additional layer must also be counted. Alpha emission rates of these materials should not be generalized, the alpha emission rates may vary be fab, process and raw material dependent.

The processed wafer alpha emission is needed to calculate the alpha SER when using accelerated testing. However, the wafer alpha emission does not need to be measured if underground unaccelerated SER testing is use to directly measure the alpha SER. This method requires a large amount of memory and a significant amount of time to obtain error counts that are statistically significant [8], but would eliminated the need to measure the wafer material emission and attenuation to calculate the alpha SER.

CONCLUSION

Since many wafers had alpha emission rates similar to or above ULA materials, we need to (a) consider the wafer contribution to the alpha flux used to calculate the alpha SER; (b) include the low alpha energy particles for alpha flux for the wafer level alpha emission and; (c) reduce the alpha contamination on or in the processed wafer.

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QUESTIONS AND ANSWERS

Q1: Did the time between fab out to alpha count make a difference?

A1: Possibly, not sure of fab out date, assume.

Q2: Please comment on accuracy of XIA, is there correlation with other measurement?

A2: Muons pulse is subtracted out (software update of XIA), attempted to correlate with Gas Proportional Counter but no clear fit was obtained.