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Specification for Low Alpha Lead in Wafer Bump Applications

Background

Alpha particles are positively charged nuclear particles consisting of two protons bound to two neutrons. Alpha particles are emitted spontaneously in some types of radioactive decay. Although alpha particle emissions are capable of penetrating only short distances, they are pernicious in creating computer memory or logic faults known as “soft faults”. Soft faults are individual events that are difficult to detect and isolate. Intel engineers working with IBM Fishkill, NY first identified the problem in 1979. The C-DIP’s (ceramic package DRAM) of that era were plated with gold and the alpha emissions were traced to the gold plated kovar package lids. Uranium or thorium decay and generate alpha particles with energies as high as 8.78 MeV. A flux of 5 MeV is capable of penetrating 25 um of silicon, resulting in 1.4 M electron hole pairs. If the electron accumulation exceeds a specific charge depending on the operating voltage and well design of the device, the cell may switch from “1” to “0”. There is no permanent damage and therefore the defect is referred to as a “soft” error. Design projections indicate that as device voltages decrease their sensitivity to alpha emissions increases.

Alpha emissions are also common from tin lead deposited in the form of bumps for flip chip applications. The potential is significant for tin lead bumps due to the number of bumps and their close proximity to the sensitive IC well structure. For example, the RISC processor in the AS400 has 2,000 tin lead bumps per die. Although the volume of the lead in the deposits is small, their proximity and numbers emit potentially troublesome quantities of alpha particles. Typical flux for conventional DRAM today is 1.0 $\alpha/cm^2/hr$. New SRAM (static) scaling and voltage make them more sensitive to alpha particles. Changes in well structure (stacked cap triple well are best) and added capacitance reduce sensitivity but add cost to wafer manufacturing. Changing to low alpha lead may be an acceptable alternative with less than or equal .01 $\alpha/cm^2/hr$ suggested as a target level. Below this level other sources of soft errors such as cosmic rays will dominate and further reductions may not be cost effective. The isotopes of tin and indium do not to emit alpha particles, and of the other under common bump alternative metals, only nickel is suspect as an alpha source.

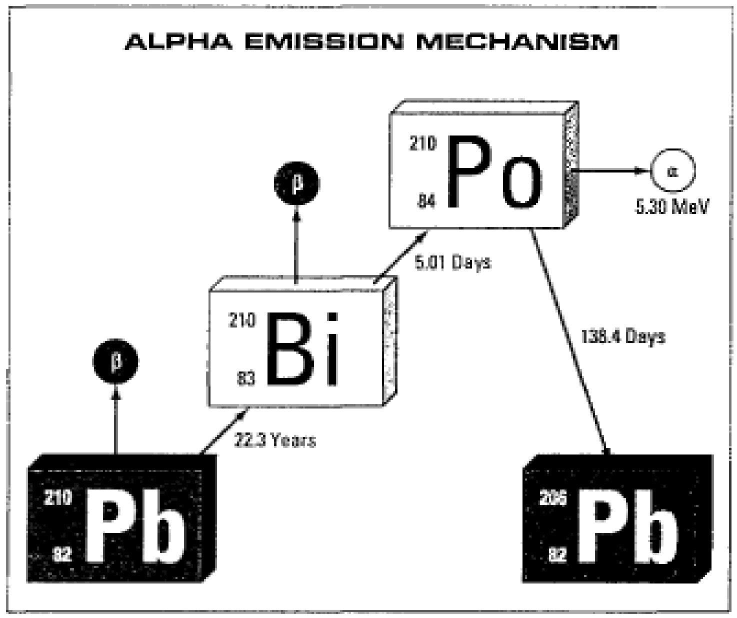
Due to the variation in product design and manufacturing technique, acceptable alpha levels vary from manufacture to manufacturer. AMD suggests that for TQFP packaging the safe level for C4 bumping is < .0015 $\alpha/cm^2/hr$. In other words, they are suggesting almost no alpha from the bump material for use on their microprocessor at all. Testing for TI memory products indicates that .03 $\alpha/cm^2/hr$ is more significant than the background cosmic count rate, thereby establishing a cut off level for significance for their memory products. Unfortunately each manufacturer must evaluate its products to define the significant thresh hold sensitivity for each type of device. Therefore, there is no industry-accepted standard for alpha emissions.

Radiochemistry

Lead occurs naturally in eight isotopic forms, of which four are stable and four radioactive. The stable isotopes, lead-206, lead-207, and lead-208, are, respectively, the end products of the uranium, actinium, and thorium series of radioactive decay; lead-204, also stable, has no natural radioactive precursors. The half-life of lead-210 is twenty-two years; it and its decay products are the principle sources of alpha particles.

Radiochemistry *(cont.)*

Bismuth has many isotopic forms including alpha emitters, most of which are short lived. Bismuth-210 is primarily a beta emitter, but decays to Polonium-210. Polonium-210 is an alpha emitter, (5.3 MeV alpha) which ultimately decays to lead-206. The decay series is predictable and alpha counts increase for 28 months from the time of smelting due to the combined emissions of bismuth, polonium, and lead in that order. This relationship is referred to secular equilibrium. During the first 28 months from smelting alpha emissions are primarily due to the decay of bismuth and polonium. After 28 months from smelting, subsequent emissions are due to alpha particles released by lead-210. In the absence of Pb-210, Po-210 would not be a problem as it is easily separated from lead during processing and its half- life is a relatively short 138 days.



Measurements

We are constantly bombarded by atmospheric nuclear decay particles; these naturally occurring decay particles are called cosmic rays. Background count levels (cosmic rays) of .005 $\alpha/cm^2/hr$ (sometimes cited at .003 $\alpha/cm^2/hr$ depend upon location) or less is generally considered safe. In order to make accurate measurements free from background cosmic rays extraordinary precautions are required. The alpha particle counting device at Lawrence Livermore National Laboratory is housed within a walk-in safe lined with six inch sheets of alpha free lead and is located 60 feet below the surface of a building dedicated to nuclear research.

Alpha counts are made using one of two classification systems, surface emissions measured in alpha counts per centimeter square, per hour, or bulk activity measured as alpha counts per day per gram of bulk weight. The conversion from surface emission to bulk count is 0.001 $\alpha/cm^2/hr$ is equal to 7 α/day/gram. Due to the diffusion of Po-210 to the surface of deposits, bulk activity is not considered accurate for IC device measurements. Although it is difficult to specify IC device threshold sensitivities, three categories of low alpha classification are generally accepted for surface emissions. Standard industrial lead is typically 10 - 100 counts/cm^2/hour, low, less than 0.3 counts/cm^2/hour and ultra low at less than 0.05 counts. There is no agreement between suppliers of low alpha lead materials concerning the terminology describing alpha emission levels. Manufacturers of IC devices and subcontractors must be careful to specify the level of alpha emissions required for their products. Some IC designs or manufacturers demand certification at or below 0.01$\alpha/cm^2/hr$, thereby approaching the level of detection for commonly accepted test methods and the naturally occurring background cosmic level. Intel cites .004 $\alpha/cm^2/hr$ as background or level of noise in the gas proportional counter method. The S/N ratio is 1.0 – 1.5:1, therefore readings at this level are suspect. Generally, acceptable S/N ratios are 10:1 or more are required to validate production quality control test methods.

Systems dedicated for the task of measuring alpha emissions are commercially available. One such device described as gas proportional counter is manufactured by Spectrum Sciences of Atlanta GA. Parts are tested with commercially available calibrated source of thorium or americium (Am-241) from a smoke detector.

Sources of Low Alpha Lead

Naturally occurring deposits of low alpha lead do not exist in nature for the reasons described above. The geology of the lead ore is the key to the selection of raw material naturally low in alpha emissions. The first criteria is age, pre Cambrian (more than 520 million years old) deposits are preferred. The second geologic factor is the amount of alpha contamination contributed by bismuth. Two domestic formations naturally low in bismuth are those of marine sedimentary origin located in the tri-states (Kansas, Missouri, and Oklahoma) and those of Ordovician volcanic origin located in Wisconsin. Ores originating from these or deposits of similar origin would be raw materials of choice. Due to the relatively long half-life of Pb-210 the longer the time from the date of smelting, the lower would be the risk from alpha emissions. This time limitation makes selection of naturally occurring deposits of lead impractical for mass marketing.

New technological advancements have provided an alternative method for the manufacture of low alpha lead. The new technique is referred to as “LISL” for Laser Isotope Separated Lead (a.k.a. AVLIS - Atomic Vapor Laser Isotope Separation). The process was developed at Lawrence Livermore National Laboratory for the separation of U-238 from Uranium. Raw material samples are heated to a vapor, which rises between two electrostatic plates. A dye laser is used to ionize the atoms of the desired isotope, which are then collected on the plates.

Additional background information about alpha radiation and its effect on electronic components is contained in review article by, J.F. Ziegler et.al. “IBM Experiments in soft Fails in computer electronics 1978-1994”, IBM Journal of Research & Development vol.40 #1 Jan. 1996.