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Adaption to scientific and technical progress under Directive 2002/95/EC

Results previous evaluation
Exemption No. 12

“Lead as a coating material for the thermal conduction module c-ring”

(Excerpt from ERA Report 2004)

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2.5 Lead as a coating material for the thermal conduction module C-ring

Lead is used as a coating material on a sealing ring used in a module at the heart of IBM's highest performance main-frame "super-computers", which are called the "Z Series". These are not used in IBM's lower specification machines or in machines made by IBM's competitors.

This exemption is requested solely by IBM as the highest performance computers made by other manufactures use different designs to make their products. IBM claims that their design has several unique advantages in speed and performance.

2.5.1 Design of equipment

The most important part of an IBM main-frame computer is an array of high performance microprocessor chips and memory chips which are mounted on a glass-ceramic substrate. To ensure the fastest signal transmission between the central processing units (CPU) and the associated memory, these devices are mounted as bare chips as close together as possible in an array with an area of 150mm square.

Figure 7 shows how the components are arranged on the substrate. The processor and memory chips generate a significant amount of heat, typically 1.4 kW. These must be cooled efficiently as the computer would cease to function if it over-heated and this is achieved by the Thermal Conduction Module (TCM). Cooling of the bare silicon chips is achieved by conduction of heat through a thermally conducting paste into a liquid cooled copper "hat". Figure 8 shows the "hat", glass-ceramic and C-ring.

IBM's latest versions contain about 16 semiconductor chips. The electrical contacts to the silicon chips are formed by hundreds of thousands of fragile solder interconnections on the active faces as Land Grid Arrays (LGA). These chips are mounted face down (i.e. flip chip) onto a glass-ceramic interconnection board at the base of the module. To ensure that the use of space is maximised and heat can be efficiently conducted away, the silicon chips are not encapsulated. As a result, the module as a whole has to be hermetically sealed to protect the active surface of the chips, to ensure that the grease does not dry out and to prevent oxidation of the bumps, silicon and chip circuitry. This is achieved with a high vacuum, which is maintained by the lead coated C-ring seal. This is a unique design used by IBM which they claim gives the best performance for their machines.

The very complex high performance chips cannot be adequately tested until they have been mounted in the module. On most of the assembled modules a small number of the chips need to be replaced to ensure the performance required. Therefore, it is necessary to replace defective chips and this means that the modules have to be dismantled, sometimes several times. The C-ring seal is inserted between the upper and lower plates of the modules to enable a demountable but sealed system.

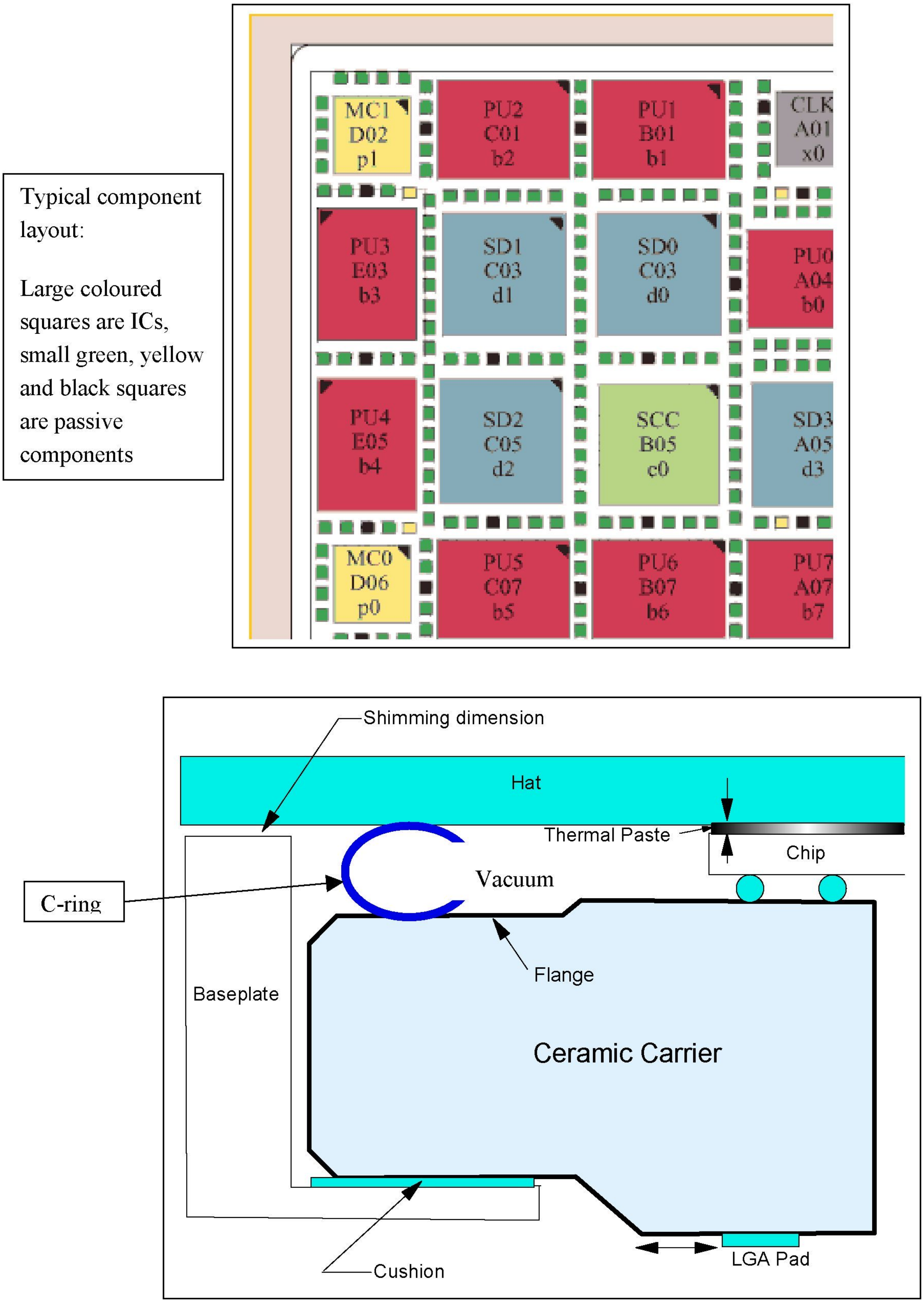

Figure 7. Thermal Conduction Module, component layout and schematic cross-section

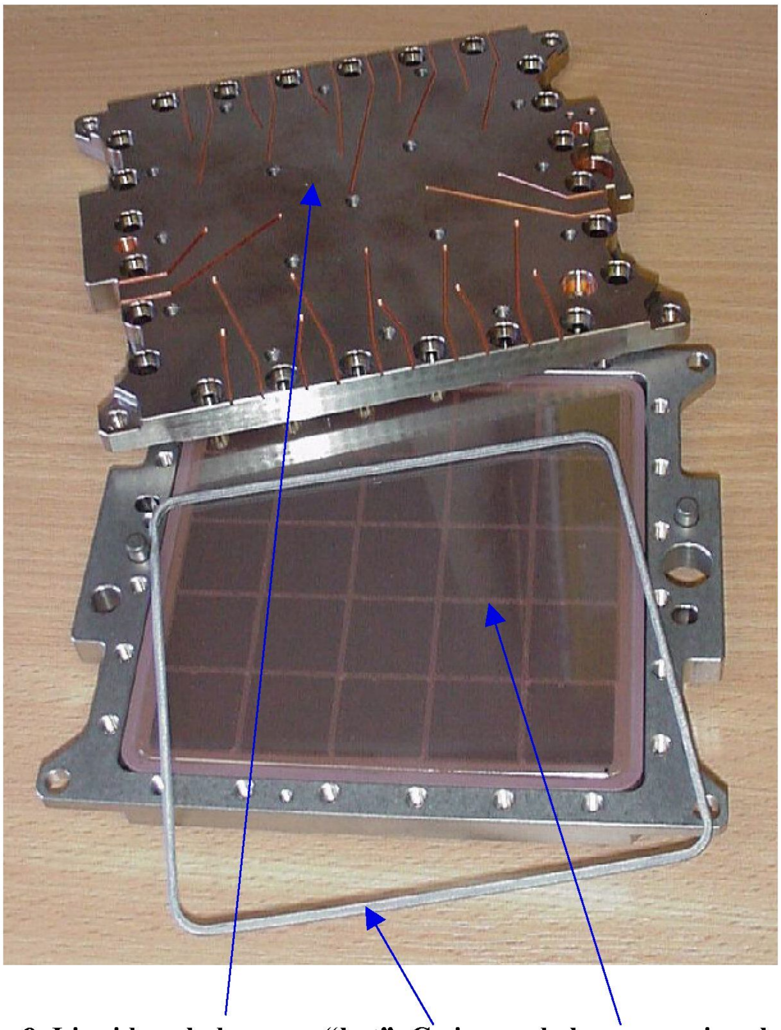

Figure 8. Liquid cooled copper "hat", C-ring and glass-ceramic substrate

2.5.2 Properties required

The sealing ring has to provide:

- A high-grade seal against air ingress – better than 10^{-8} atm-cc/sec. These are the levels used in aerospace grade semiconductor devices in individual packages. A vacuum must be maintained for up to 30 years.

- Sufficient flexibility to accommodate the spread of heights in the devices and to allow for changes in spacing between the plates due to differences in thermal expansion coefficient of the materials, while the module heats and cools during use.

- There is a large difference in TCE between the copper "hat" and the glass ceramic. The TCE of copper is 16 ppm/°C whereas the glass ceramic is designed to match silicon at about 2.5 ppm/°C. This results in significant sideways movements as the temperature changes and it is essential for the lead surface to slide across the surfaces during these movements without breaking the hermetic seal. This performance must be maintained over tens of years without significant wear.

- As there are many die in each module and these cannot be pre-tested, it is essential that any faulty die can be replaced after testing and the module re-assembled while maintaining the position of the parts.
- Construction of modules must be straightforward, as complex procedures tend to cause a larger proportion of defective product.

The C-ring seal is square with rounded corners, where the cross section of each arm is a "C" shape. C-rings are a common type of seal for retaining high vacuum and are available commercially with a variety of coatings. The "C" shape allows for compression without large lateral movement. The material of the IBM seal is Inconel, which is electroplated with pure lead which provides the seal against the upper and lower plates. The lead is coated with a mixture of waxes to assist the sealing and sliding. The lead has a thickness of 63 to 115 µm with a total average amount of lead of 3.1 g per seal. The total consumption of lead in this application by IBM is estimated to be about 10 kg per year. This includes about 150 g of lead per year (world-wide) on seals used for repair.

2.5.3 Alternatives

During development by IBM, many other plating materials were evaluated. Those examined and their disadvantages include harder and softer materials. The harder metals were:

- Gold - too hard and did not retain the vacuum in tests by IBM.
- Silver - prone to tarnishing and also did not retain a vacuum.
- Lead-tin - harder than pure lead. Also, tin suffers from fretting, where the surface, freshly exposed after each movement, oxidises. The tin oxide builds up to an irregular layer, which disrupts the hermetic seal.

The softer material examined was indium, which makes a good seal initially but is deformed more than lead so that it did not retain a vacuum. Indium under pressure will adhere to a glass or ceramic surface which will prevent sliding during temperature changes. It is also prone to corrosion especially in the presence of traces of chlorine.

IBM also examined other sealing materials, which included:

- Elastomer O-rings
- Metal O-rings
- Elastomer gaskets
- Metal gaskets
- Composite gaskets
- Plated elastomers.

All of these failed to meet the full set of requirements due to high gas leak rates, low initial yield, aspect ratio limitations, tolerance control, high wear rate, poor thermal cycling performance, and loss of normal force, which balances the pressure to the Land Grid Arrays to ensure electrical contact to the semiconductor devices. It is well known that all polymers are porous to gases and so will not permanently retain a vacuum and so can be used only if continuous pumping with a vacuum pump is used which is not practical with these modules as well as significantly increasing the energy used.

Only IBM use C-ring seals in their multi-chip modules for their "high end" systems. Their competitors use completely different designs in their equivalent products. It should be noted that only modules that generate very large quantities of heat require the complex designs that maximise cooling. Most computers produce less heat so that vacuum seals are unnecessary.

The top of the range computers are very complex devices which take many years to develop and, clearly, each manufacturer will use their own proprietary designs and each will believe that theirs are the "best" but IBM's competitor's designs do not require lead coated C-rings. IBM claim to have about 70% of the market for high-end computers and this indicates that the design they have developed is successful. It is very unlikely that IBM would be able to identify an alternative coating to lead and its elimination could be achieved only by significant design changes, which will take many years of research bearing in mind how long the current design took to develop.

2.5.4 Future plans

IBM is already carrying out research into its next generation of Z Series computers. This will take many years of research but IBM are planning to replace their computers that use the TCM modules (which use the lead coated C-ring) with new Z Series computers some time in 2009. After that date there will be a common architecture over the IBM 1, P, X and Z Series computers. These will use far fewer semiconductors chips which is possible because new much more complex chips will replace the functionality of several chips that are currently used. This is a continuation of the trend that has been progressing for many decades. Originally the Z Series TCM had 133 chips but in 2004 this has fallen to only 16. Since far fewer chips will be incorporated into the TCM from 2010, there will not be the same packaging and rework constraints and IBM should be able to phase out the C-ring in future designs.

IBM will need to continue to supply lead coated C-rings after 2009 for repair of machines built before this date. The RoHS Directive allows the use of spare parts containing restricted substances for the repair of equipment put onto the market before 1st July 2006 but this would not automatically apply to products put onto the market after this date but which contain an exempted component (such as the C-ring) and so this exemption request is for the use of lead coated C-rings in new computers until 2010 and lead coated C-rings after this date for the repair of equipment put onto the market until 2010.

2.5.5 Summary of the case for an exemption

Lead provides a unique combination of properties for this application by IBM. No alternative material has been found despite extensive research. This exemption can expire at the end of 2009 when IBM plan to have phased out lead-coated C-rings by a change in module design. The request for the exemption is made on the assumption that this includes the allowance for repair of computers with this material after 2010.

connections to PCBs without soldering but which can be removed and re-inserted without damage to the connector or the PCB.

4.5 Lead as a coating material for the thermal conduction module C-ring

Thermal conduction modules are the central processor units used in the Z-Series main-frame computers produced by IBM. The C-ring is the seal used between the glass-ceramic circuit and the liquid cooled copper plate, which is used to remove heat from the semiconductor chips.

4.6 Lead and cadmium in optical and filter glass

Optical components used in electrical equipment such as glass lenses, optical filters and prisms where no lead-free alternative is suitable. Lead in the glass of electronic components is not included in this exemption as this is covered by item 5 of the Annex of the RoHS Directive.

4.7 Optical transceivers for industrial applications

This exemption request was made to cover optical transceivers and the solder connections made to the PCB to which they are attached. Optical transceivers convert optical signals into electrical signals using glass-fibre connected to a photosensitive semiconductor, convert electrical signals into optical signals using a laser diode or LED attached to an optical fibre or one device may contain both functions.

4.8 Lead in solders consisting of more than two elements for the connection between the pins and the package of microprocessors with a lead content of more than 85% in the proportion to the tin-lead content (exemption until 2010)

A lead-based solder with a melting point higher than standard lead-free solders and eutectic tin/lead but containing <85% lead which is used to attach pins to the carriers of microprocessor packages. This alloy is not covered by the exemption listed as item 7.1 of the Annex of the RoHS Directive which is for solders which contain >85% lead (see section 1.3).

4.9 Lead in high melting temperature type solders (i.e. tin-lead solder alloys containing more than 85% lead) and any lower melting temperature solder required to be used with high melting temperature solder to complete a viable electrical connection

This exemption is intended for internal (Level 1) connections made between the semiconductor die and the carrier in flip-chip packages which have higher power consumption and currently use high melting temperature solder bumps (>85% lead) which are connected to the carrier with eutectic tin/lead (~37% lead). The bump composition will have <85% lead. This exemption would also include situations where high melting point solder balls (e.g. on ball grid array packages) are attached to a PCB with a lead-free solder. It is <u>not</u> intended to permit the use of solders containing lead for