

Applications of Osprey Lightweight Controlled Expansion (CE) Alloys

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Abstract

Osprey CE Alloys are finding increasing use in the electronics and allied industries for a variety of applications. These light-weight alloys are composed of silicon-aluminium and their coefficient of thermal expansion (CTE) can be controlled to a chosen value between 7.5 and 20 ppm/°C, simply by adjusting the proportions of these two constituents. CE Alloys can be machined to tight tolerances using standard machine tools and plated with nickel, gold or silver finishes using standard processes. The advantageous physical properties and manufacturing characteristics of these alloys are being exploited in a variety of electronic applications. The ability to tailor the CTE values of the CE Alloys to ceramic circuit boards and components operating at high frequencies, combined with their lightness, high thermal conductivity, dimensional stability and manufacturability, have made them a favoured choice for RF/microwave packages and carriers and also for heat sinks, where these materials have a distinct cost advantage over copper-molybdenum and copper-tungsten. The additional benefit of high stiffness has made CE Alloys with the lower CTEs eminently suitable for optical and opto-electronic housings. On the other hand, the higher thermal expansion CE Alloys are being increasingly used in carrier plates for laminate PCBs, guide bars for circuit boards, and jigs and fixtures in semiconductor processing equipment and soldering ovens. The unique combinations of properties of CE alloys that make them the preferred choice for a growing range of applications are described and illustrated in this paper.

Key words: heat-sinks, packaging, carriers, materials, light weight, controlled expansion, electronic housings, microwave and RF assemblies, optical packaging

Introduction

Osprey silicon-aluminium alloys are in growing demand for a variety of applications in the electronics and allied industries. These alloys are available in the composition range 70Si-30Al to 12Si-88 Al, which enables the coefficient of expansion to be adjusted between 7.4 and 20 ppm/°C (see **Table 1**), so as to be compatible with many common microelectronic devices and substrates. A 5 ppm/°C grade alloy of 85Si-15Al composition is also under development.

These alloys are typically between three and six times lighter than established packaging and baseplate materials used in RF and microwave products such as Kovar®, copper-molybdenum and copper-tungsten. At the same time, the Osprey CE Alloys offer greatly superior thermal conductivity compared to Kovar® – a vital requirement for meeting the increased power loading requirements of the latest generation of devices and associated circuitry. They possess high specific stiffness, but are not unduly hard, so are amenable to standard machining operations, such as milling and drilling, and are as easy to machine by EDM as aluminium. Machining operations do not produce burrs on the higher silicon CE Alloy parts, in contrast with most other metals, and this obviates the need for operations to remove them. CE Alloys are readily platable, using industry proven methods. Being composed of silicon and aluminium, the alloys are environmentally friendly, safe to handle and use, and present no disposal problems. As they do not contain strategic metals, such as cobalt, tungsten and molybdenum, CE Alloys are far less susceptible to price volatility and supply shortages. For example, the price of molybdenum has increased by a factor of ten since the beginning of 2004.

Their unusual combination of high thermal conductivity and low thermal capacity makes for easier soldering of feedthroughs, because heat is distributed more evenly in CE alloy assemblies [Private communication, Thunderline Z, USA]. Because aluminium and silicon are light metals, soldered regions, comprising heavy metals, are readily revealed by X-rays, greatly facilitating non-destructive inspection of joints. Some of the relative benefits of the CE alloys over alternatives are summarised in **Table 2**.

CE Alloy designation	Alloy composition	CTE, ppm/°C, 25-100°C	Density, g/cm ³	Thermal Conductivity at 25°C W/mK	Bend Strength, MPa	Yield Strength, MPa	Elastic Modulus, GPa
CE20	Al - 12%Si	20.0	2.70				
CE17	Al - 27%Si	16.0	2.60	177	210	183	92
CE17M	Al - 27%Si*	16.0	2.60	147			92
CE13	Al- 42%Si	12.8	2.55	160	213	155	107
CE11	Si - 50%Al	11.0	2.50	149	172	125	121
CE9	Si - 40%Al	9.0	2.45	129	140	134	124
CE7	Si - 30%Al	7.4	2.40	120	143	100	129

*CE17M also contains minor additions of Fe, Mg and Mn

Table 1. Standard Osprey Controlled Expansion (CE) Alloys and a selection of their physical properties

CE alloy	Benefits of CE alloy	
	Compared with:	Benefits
CE17	Aluminium Copper	26% lower CTE, stiffer, 10% weight saving, excellent machinability Less than $\frac{1}{3}$ the weight, stiffer, stronger, same CTE
CE13	Aluminium Copper	43% lower CTE, stiffer and lighter Almost $\frac{1}{4}$ the weight and stiffer
CE11	Steel	Less than $\frac{1}{3}$ the weight, almost 3x higher thermal conductivity, same CTE
CE7	Copper-85% molybdenum Copper-85% tungsten Kovar® Titanium Al-65%SiC	$\frac{1}{4}$ the weight, same CTE, cheaper $\frac{1}{6}$ the weight, similar CTE, considerably cheaper Less than $\frac{1}{3}$ the weight, 7x thermal conductivity, similar CTE Over 7x higher thermal conductivity, $\frac{1}{2}$ the weight, similar CTE Easy to machine and electroplate, modest weight saving of 20%, similar CTE, no NRE costs for dies
CE7 / CE9	Be-BeO	CE alloys are non-toxic – only contain Si, Al, Easier to strip off platings and rework / replate; similar CTE

Table 2. Relative benefits of selected Osprey CE alloys compared with other materials used for high-frequency electronic packages and baseplates

Applications

The beneficial properties of the CE alloys are being exploited in a wide variety of applications. These are described below and summarised in **Table 3**.

RF and Microwave packaging

CE13, 9 and 7 are being widely used for microwave packaging for space and aerospace applications at operating frequencies as high as the Ka band (with an upper limit of 36 GHz), taking advantage of: their reasonably close CTE match to circuit boards and components, their high thermal conductivity, low density, hermeticity, dimensional stability and ease of manufacture. While the CTE of CE11 is noticeably higher than that of alumina, which is widely used as substrates for microwave and RF circuits, it is far lower than that of aluminium. More pertinently, it is sufficiently close in its CTE to alumina for moderately compliant conducting adhesives to take up mismatch stresses without compromising the adhesion or fracturing the alumina substrates.

One example is a transmit and receive modules operating at super-high frequencies (SHF), in the 3-30 GHz range of the microwave region housing of CE11, which is being developed as a replacement for one of titanium used by Raytheon (see **Figure 1**) [Weinshanker et al., 2004]. Titanium possesses a poor thermal conductivity and is twice the weight of CE11; also, molybdenum-copper inserts have had to be introduced as heat spreaders to remove heat generated by active devices, which adds cost and complexity to their manufacture. By comparison, CE11 possesses a relatively high thermal conductivity, which enables the expensive molybdenum-copper inserts to be dispensed with, and an overall cost reduction in the housing. The circuitry is mounted on alumina substrates, which are attached to the base of the housing with a conductive adhesive that is tolerant to the CTE difference. Raytheon and PAC, their packaging house, are also able to benefit from their ability to use the a standard laser welding process for joining the aluminium sleeves of sealed feedthroughs to the packages and satisfy the requisite MIL-STD-883E specification on hermeticity. They have verified that the gold-over-nickel plated CE11 packages pass the industry standard MIL-C-5541 salt spray corrosion tests.

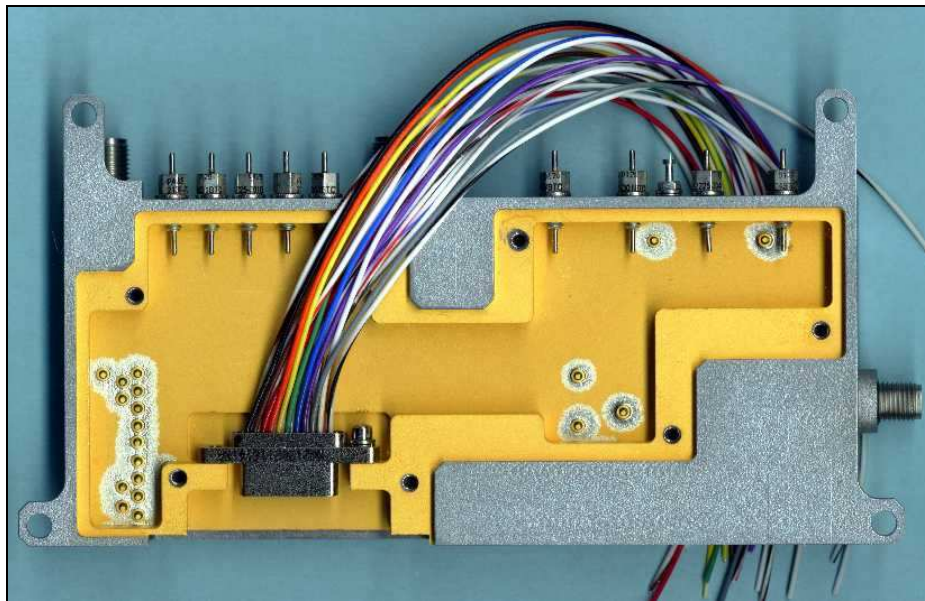


Fig. 1. Fully manufactured base of a CE11 package (courtesy of Pacific Aerospace and Electronics, and Raytheon Space and Airborne Systems)

CE13 has been chosen by Ericsson Microwave Systems AB as a replacement for Kovar® for a radar housing (see **Figures 2(a)** and **2(b)**). The CE alloy offers the weight reduction that they required for this part, which rotates in use, and as with the Raytheon housing, heat spreaders needed with Kovar® are no longer required. The circuitry is assembled on a CE9 carrier, machined with threaded holes and plated with nickel. This is then bolted down into the CE13 housing, which is also nickel-plated, and the circuitry is tuned. Two lids of CE17 are fixed to the top and bottom of the CE13 housing to cover the screw holes, and laser welded in place to provide a hermetic seal. The nickel layer is skimmed off the areas of the joint areas to avoid compromising the mechanical integrity of the weld arising from nickel in the weld. The weld has been shown to be fully reproducible and allows for reworking.



Fig. 2. (a) CE13 housing; (b) complementary lid in CE17 plated with gold, used for radar application (courtesy of Ericsson Microwave Systems AB)

Tyco M/A-Com has adopted CE11 for a hermetic microwave amplifier housing in aerospace applications, taking advantage of the lightness of this material and not having to incorporate a heat-spreader, which would have been necessary were Kovar® or titanium used instead, thereby resulting in significant space saving (see **Figure 3**). A steel shim is soldered to this package, and a steel lid is resistance seam-sealed onto it. This solution offers excellent reproducibility, resulting from the high consistency of spray-formed CE11 and the associated processing, which is responsible for a high yield of this item.

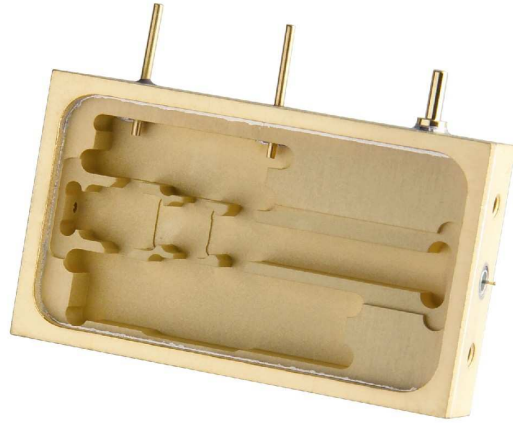


Fig. 3. Microwave amplifier housing for aerospace application (courtesy of Tyco M/A-Com)

RF and microwave carriers

CE Alloys are favoured for carriers of microelectronic circuitry in preference to copper-tungsten and copper-molybdenum on account of its much reduced weight and cost.

For example, C-MAC has gained these benefits by substituting carriers of CE7 for 10Cu-90W in Lucent's 40 Gbit/sec transmit modules. The manufacturing route has also been simplified in that the carriers bear plinths for active microwave devices, which have to be located to a precision of 20 μm ; see **Figure 4**. When C-MAC used carriers of Cu-W, machining limitations of that material obliged them to produce the plinth as a separate item, which then had to be soldered onto the body of the carrier. This complication made it impossible to reproducibly achieve the requisite tolerances, and moreover introduced a soldered joint, which reduced the effectiveness of the Cu-W carrier as a heat sink. The carrier is now produced in CE7 as a single part with an integral plinth, owing to the excellent machining characteristics of CE alloys, with the added benefit of high edge resolution of features and a high degree of flatness.

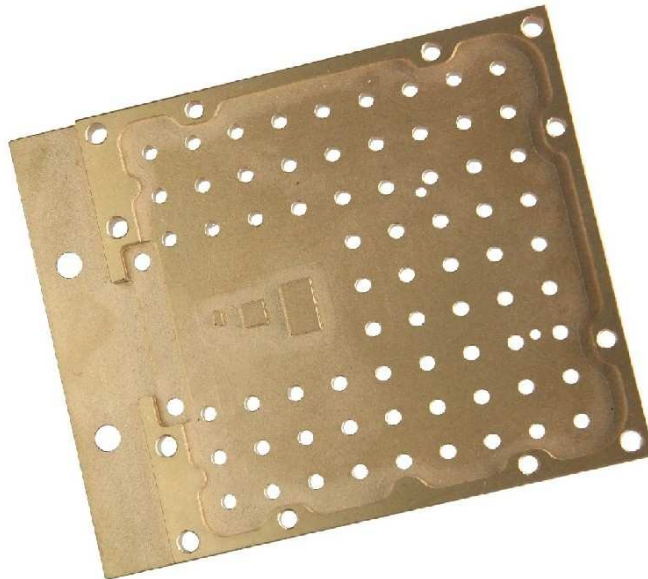


Fig. 4. CE7 transmit module carrier for 40 Gbit/sec operation (courtesy of C-MAC)

Optical housings

CE Alloys are suitable for hermetic optical and opto-electronic housings, on account of their close CTE match to components, their almost constant thermal expansivity over a normal range of operating temperatures, high thermal conductivity and stiffness, and good manufacturability.

For example, **Figure 5** shows an optical housing in CE7, which forms part of a high speed MEMS switching device, comprising an array of these modules, used in aerospace applications. The housing receives laser inputs and supports a series of mirrors supported by arms screwed into the walls of the housing. It replaces a similar item that was manufactured in stainless steel, which suffered from a number of drawbacks. CE7 provides a lower CTE, a welcome reduction in weight, improved stiffness and rigidity, and stays flat. The housing is plated with gold over nickel and during assembly is manually tuned by careful adjustment of the mirrors, which are then fixed in position by soldering the supporting arms to the housings. A particular problem with the stainless steel housings was the difficulty in tuning them owing to relative movement of the mirrors when the soldering operation is carried out, because the steel does not stay flat during the thermal excursion. By comparison, CE7 is dimensionally stable, so that this problem does not arise.



Fig. 5. CE7 optical housing for a switching device in an aerospace application

Thermal backing plates for laminate boards

Sheets of Osprey CE alloys (CE17 down to CE11) are being used as backing plates with laminate PCBs formulated for high frequency use. These boards possess a polymer matrix, normally a hydrocarbon thermoset or PTFE (Teflon). They are filled with a ceramic to provide a tight control of dielectric constant, low loss, and good temperature stability of dielectric properties. Additionally, woven glass reinforcement is added to improve stiffness (especially in the case of PTFE which, on its own, is soft and flexible) and reduce the CTE in the x-y plane. CE alloy backing plates are available in sizes up to 20 x 20 inches, and down to 3 mm in thickness. Developments are also in progress to produce larger plates down to 1 mm thickness. Plates of up to 6 x 6 inches in area can be sliced to approximately 0.5 mm in thickness.

A metal backing enhances stiffness and also provides a remedy for the inferior thermal conductivity of polymer laminates, when coupled with conducting vias through the board. Copper, brass and aluminium have been used for the backing plates, but each of these has disadvantages in comparison with the CE Alloys. Aluminium represents the cheapest option and is also lightweight. However, the CTE mismatch between aluminium and the laminate board is typically 6 ppm/°C, which is sufficient to be responsible for

yield losses in manufacture and bowing and twisting when the temperature changes, even within its normal operating range ($-40^{\circ}\text{C} - 80^{\circ}\text{C}$), which can generate component failures. Copper is the preferred for optimum thermal management, but is heavy and insufficiently stiff. Brass is selected for improved stiffness but it is similarly heavy and its CTE mismatch to the laminates is significant ($\sim 3 \text{ ppm}/^{\circ}\text{C}$). By contrast, CE17 offers an optimum solution, combining good CTE match, lightweight, high thermal conductivity and high specific stiffness. Its relative stiffness enables the laminate substrate to be made thin and thereby reduce microwave and RF dispersion and radiation losses. An example of a CE17-backed laminate board for a base-station application is shown in **Figure 6**.

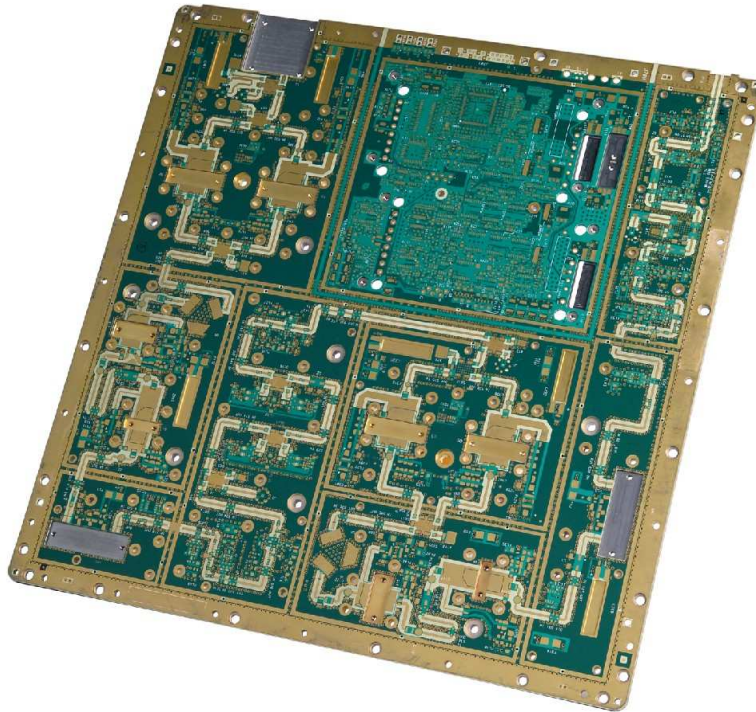


Fig. 6. CE17-clad laminate PCB for a base-station application

Guide-bars for PCBs

Strips of CE17M are used as guide-bars for PCBs in aircraft and in embedded computer products, as a replacement for the same items in W-50Cu, being a quarter of the price and only one-sixth of the weight. Radstone Technology, a prime user of CE17M guidebars, has also gained a 50% reduction in their procurement cycle by their substitution for parts in W-50Cu.

The CE17M grade alloy has small additions of iron, magnesium, manganese added to the aluminium-silicon, to improve hardness and machinability. The guide-bars in this material are stiff and locally constrain the CTE of the PCBs, and thereby reduce the CTE mismatch of solder-attached silicon devices, which also results in significant improvements to fatigue life.

Recesses are machined on one side of the guide-bars, which are gold plated. Copper-clad projections on the PCBs are fitted into these recesses and soldered in place. The even side of the guide-bars are hard nickel plated for good wear resistance when the boards are slid into racks and then mechanically fastened down. Guide bars, which are being produced for Radstone Technology, are illustrated in **Figure 7**.



Fig. 7. CE17M guide-bars replacing tungsten-copper in PCBs used in aircraft (courtesy of Radstone Technology)

Carriers for sensors

CE7 is being used in carriers for sensors, as a replacement for Cu-W. The specific benefits of the CE alloys for these applications are an excellent CTE match to sensor devices, high thermal conductivity to provide good heat sinking, stiffness, flatness, and superior machinability to close tolerances, including crisp edges. In this application, a peripheral recess in the carrier has to be machined to a high finish, to house an O-ring for a vacuum seal, as shown in **Figure 8**. This particular sensor is used in a mobile military application, where the weight-saving over Cu-W is of major benefit.

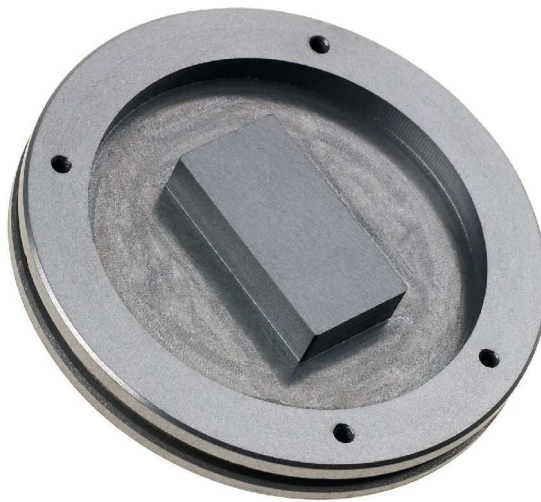


Fig. 8. CE7 carrier replacing tungsten-copper in a lightweight sensor for a military application

Heat sinks and spreaders, and microwave filter components

Other important applications of CE Alloys include heat sinks and spreaders for power modules and discrete devices and also microwave filter components, which take advantage of the beneficial characteristics enumerated in **Table 3**.

Lens holders for laser systems

CE9 lens holders, machined to close tolerances and shown in **Figure 9**, are being used in a laser system by Teledyne Electronic Technologies in aircraft surveillance. These components benefit from close expansion matching of CE9 to the lens materials and its high stiffness.



Fig. 9. Lens holders of CE9, used in a laser system (courtesy of Teledyne Electronic Technologies Inc.)

Components for semiconductor processing equipment and other low inertial applications

CE13 is being used in pick-and-place assemblies in semiconductor processing equipment and other mechanical systems where low inertia is required. CE alloys are eminently suited for such applications, on account of their unusually high specific stiffness (stiffness/weight ratio) and low thermal expansivity.

Soldering assembly fixtures

CE13 alloys are being used in soldering fixtures in Flip Chip and Ball Grid Array (BGA) production lines. A fixture for ball grid arrays is shown in **Figure 10**. The controlled thermal expansion of these alloys at elevated temperature is accurately predictable. This helps in precise positioning and soldering of the solder balls in IC assembly lines. Combined with its resistance to chipping and ease of machining to tight tolerances in an application where high precision of feature definition is required, CE13 alloy is a preferred choice over graphite. CE13 offers the further advantage of a superior wear resistance, which results in an enhanced service life and of combining a high thermal conductivity with a low heat capacity, to ensure that a uniform temperature distribution is achieved rapidly.

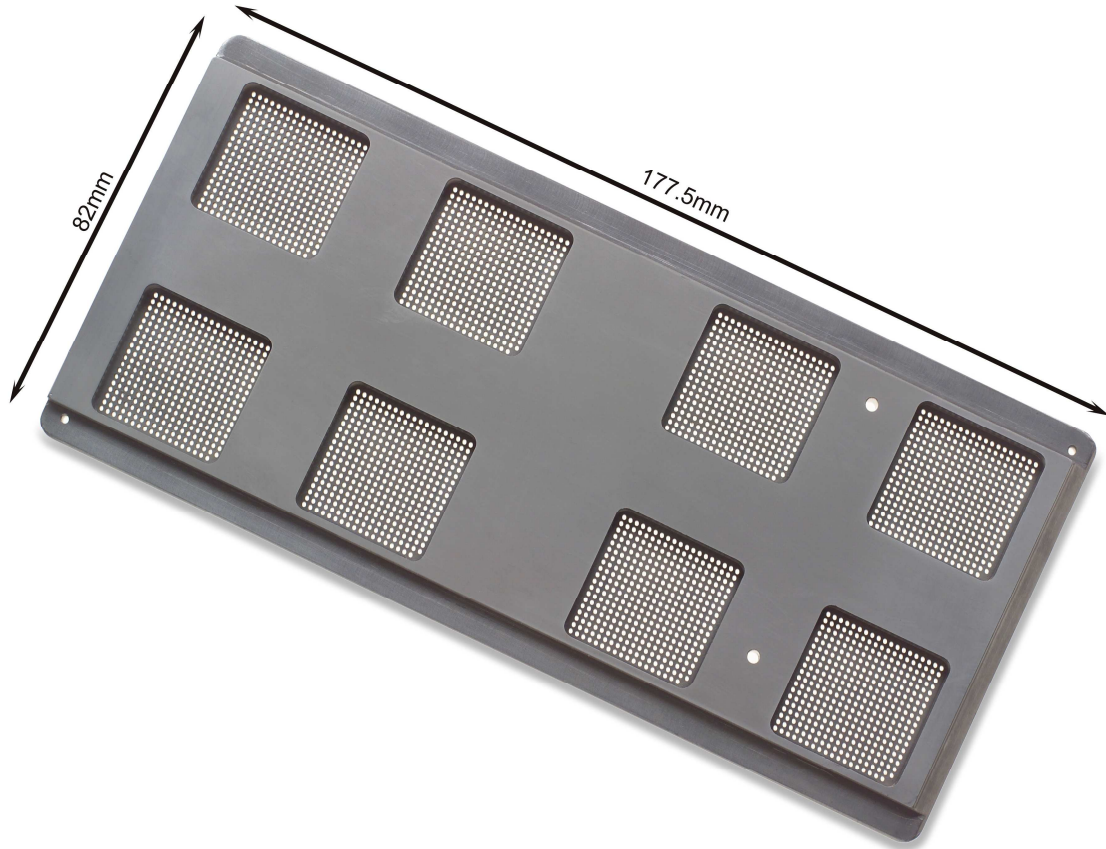


Fig. 10. Fixture of CE13 for soldering ball grid arrays (courtesy of PTC Pte Ltd, Singapore)

Conclusions

Osprey CE Alloys offer application solutions, which enhance product performance reliability, increase the functionality-to-weight ratio and are cost competitive. They lend themselves to manufacture by standard machining and plating procedures. The favourable combination of processing capabilities of these alloys present flexible opportunities for the manufacture of diverse products. CE alloys are available in the form of plates and blocks, or machined and plated components, ready for manufacturing into different products. See **Table 3** and refer to the www.smt.sandvik.com/osprey and www.cealloys.com websites.

Application	Beneficial Properties of CE Alloys
RF/micro-wave packages and carriers	<ul style="list-style-type: none"> • CTE can be selected for close match to circuit boards and components (e.g. CE7, 9) or to be sufficiently matched when using a compliant adhesive (e.g. CE11, 13, 17) • High thermal conductivity • Light weight • Hermeticity • Dimensional stability, flatness, no/ minimal burrs • Manufacturability (machining and plating)
Optical and opto-electronic housings	<ul style="list-style-type: none"> • CTE match to components (e.g. CE7, 9), or sufficiently compliant (e.g. CE11, 13, 17) • High thermal conductivity • Stiffness • Hermeticity • Manufacturability (machining and plating)
Carrier plates for laminate PCBs	<ul style="list-style-type: none"> • CTE match to PCBs (e.g. CE13, 17) • High thermal conductivity • Cost and weight advantage over copper • Manufacturability (machining and plating)
Guide bars for PCBs and embedded computer products	<ul style="list-style-type: none"> • CTE match to PCBs (e.g. CE17M) • Stiffness • Light weight • High thermal conductivity • Manufacturability (machining and plating)
Carriers for gas and other sensors	<ul style="list-style-type: none"> • CTE match to electronic dies and sensor devices (e.g. CE7) • High thermal conductivity • Stiffness
Heat sinks and heat spreaders	<ul style="list-style-type: none"> • Low CTE (e.g. CE7, 11, 13) • High thermal conductivity • Cost advantage over W-Cu and Mo-Co
Lens holders in laser systems	<ul style="list-style-type: none"> • High specific stiffness (stiffness/weight ratio) of CE9 • Close expansion match to lens glass
Semiconductor processing equipment	<ul style="list-style-type: none"> • High specific stiffness (stiffness/weight ratio) (e.g. CE13) • High thermal conductivity compared with steels
Soldering assembly fixtures	<ul style="list-style-type: none"> • Good wear resistance compared with graphite (e.g. CE13) • Good machinability • High thermal conductivity

Table 3. Applications of CE alloys and the beneficial properties that they exploit.

Reference

Weinshanker, S., et al., 2004. 'High Performance, Lightweight, Hermetic AlSi Packages for Military, Aerospace, and Space Applications,' 2nd *Advanced Technology Workshop on Military, Aerospace, Space, and Homeland Security: Packaging Issues and Applications*, Baltimore, 29 March 2004

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