Preparation and Properties of In-Situ Devices Using the SALD and SALDVI Techniques

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One of the many advantages of Selective Area Laser Deposition (SALD) and Selective Area Laser Deposition Vapor Infiltration (SALDVI) is that they can be used to embed in-situ micro-sensors within macro-components. A single-point SiC/C thermocouple sensor embedded within a SiC macro-component and electrically insulated with silicon nitride layers has been demonstrated[1]. In many applications, multi-point sensors within a single component are needed, e.g., in monitoring the temperature gradient and distribution at different positions. In this paper, multi-point thermocouple devices are demonstrated. The macro-component is a SiC bulk shape made by infiltrating vapor deposited silicon carbide into a silicon carbide powder bed using the SALDVI technique. Multiple SiC/C thermocouples are embedded in-situ in the SiC bulk shape using the SALD technique. The transient and steady state responses of the embedded thermocouples are compared to reference thermocouples probing the surfaces of the bulk shape.

Introduction

Selective Area Laser Deposition (SALD)[2] and Selective Area Laser Deposition Vapor Infiltration (SALDVI)[3,4] are two Solid Freeform Fabrication (SFF) techniques utilizing gas precursors. Gas phase approaches to SFF are based on the concept of building structures by depositing solid material from reactive gases[5-7]. The chemical vapor deposition reaction in these processes is localized using a laser beam, and the gas composition and processing conditions can be selected to achieve a desired chemistry in the vapor deposited material. SALD deposits material directly from the gas phase to create overall structures. In SALDVI, the vapor deposited material infiltrates a layer of powder, forming a continuous matrix between the powder particles to build shapes.

The ability to deposit combinations of vapor deposited material from different gas precursors and in arbitrary patterns by a scanning laser beam is a key feature of SALD and SALDVI in fabricating multiple material devices such as thermocouples which can be embedded into a bulk shape. The fabrication of functional SiC/C thermocouples deposited by SALD on several substrates have been described and demonstrated[8]. SALDVI fabricates multiple layer shapes of SiC particles in a matrix of vapor deposited SiC[4]. This paper describes how the two techniques are used to embed multiple SiC/C thermocouples into a bulk SiC shape and reports its performance in response to an applied temperature gradient.

SALD of SiC/C Thermocouples

A detailed account of precursor selection and processing conditions related to the fabrication of SiC/C thermocouples using SALD is presented elsewhere[1]. Here a general overview of the procedure is presented. The SiC/C thermocouple package consists of three materials all of which are deposited from gas precursors using the SALD technique: silicon carbide, carbon, and silicon nitride. Figure 1 shows a schematic of the thermocouple, both in an exploded view and as fabricated, showing the location of the three SALD materials. First, a

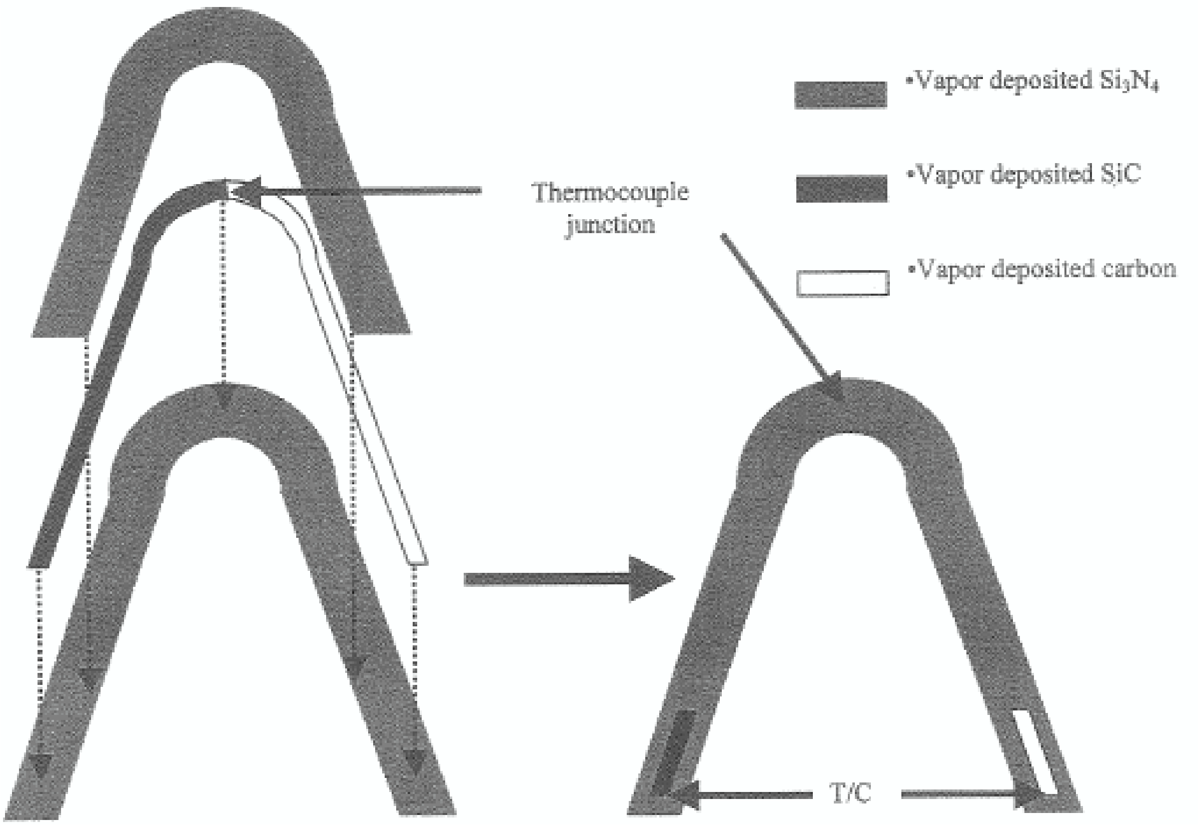

Figure 1. Fabrication of the SiC/C thermocouple device using the SALD technique.

layer of Si_3N_4 is deposited from a gas mixture of tetramethylsilane and ammonia. Next a line of SiC is deposited from tetramethylsilane and a line of carbon is deposited from acetylene. The point where the two lines meet defines the temperature sensing junction of the SiC/C thermocouple. Finally a second layer of Si_3N_4 is deposited over the SiC/C thermocouple, leaving a portion of each leg exposed for attaching probes to measure the emf. The Si_3N_4 layers are necessary to electrically insulate the thermocouple legs from the bulk shape into which the device will be embedded.

Embedding Thermocouples into a Bulk Shape

Figure 2 shows a schematic and actual view of a multiple layer bulk shape containing two thermocouples embedded at different locations through the thickness. SALDVI is used to fabricate a bulk shape by infiltrating layers of SiC powder with vapor deposited SiC. At an appropriate intermediate layer in the bulk shape, a thermocouple device as described in Figure 1 is deposited directly onto the SALDVI layer using SALD. Additional SALDVI layers are added on top of the SALD thermocouple device, embedding it into the bulk shape. The process is repeated in this fashion to achieve the desired number of layers.

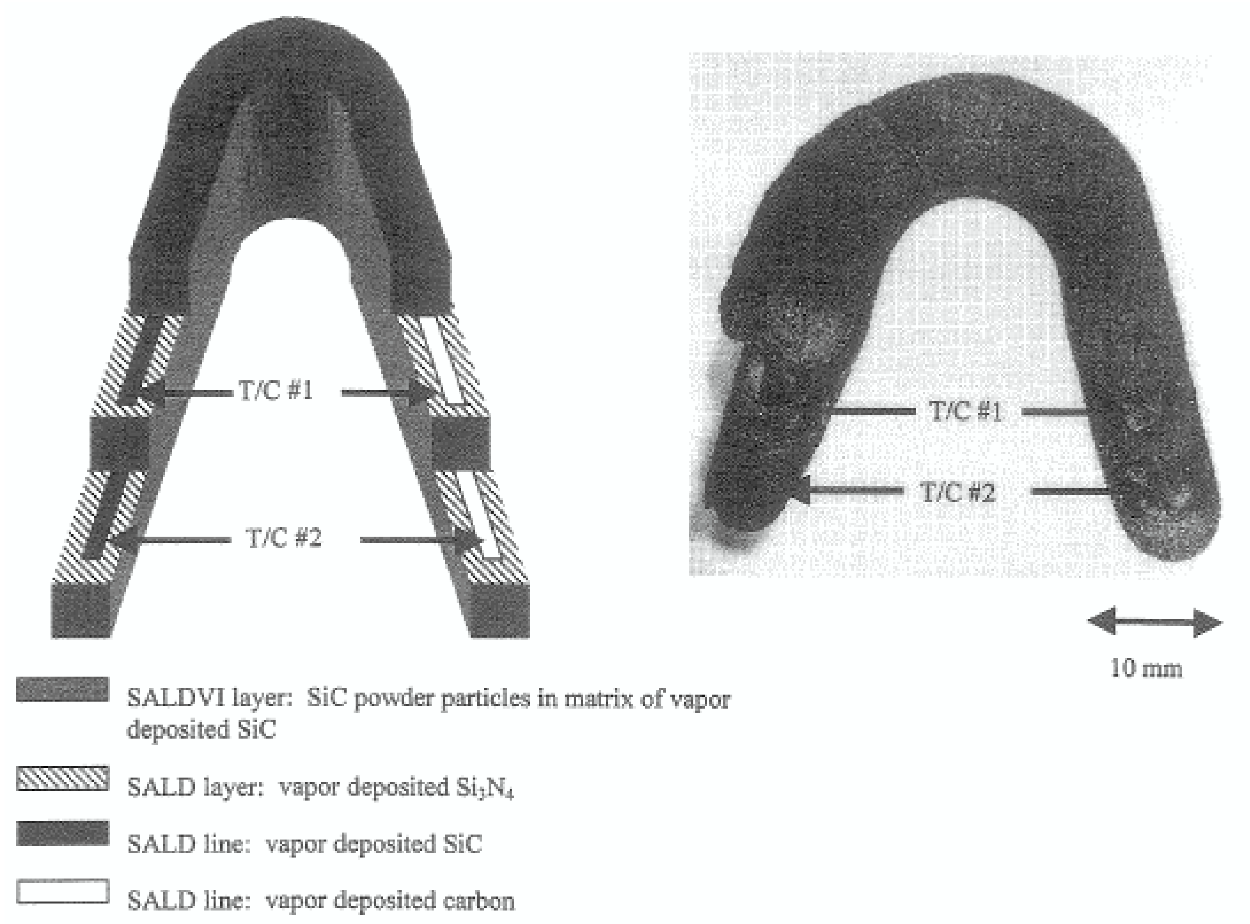

Figure 2. Bulk SiC shape containing two embedded SiC/C thermocouples

Performance of Embedded Thermocouples

A temperature gradient was applied through the thickness of the bulk shape from Figure 2 to test the response of the two embedded thermocouples. The top surface of the shape directly above the thermocouple junctions was locally heated with a laser. K-type reference thermocouples were attached to the top and bottom surfaces of the bulk shape, also directly above and below the locations of the embedded thermocouple junctions. The laser power was systematically varied to check the transient and steady state emf signals from the two SALD SiC/C thermocouples. The response of the embedded thermocouples is plotted in Figure 8 against the two reference K-type thermocouples.

The top K-type reference thermocouple measures the thermal history applied by surface heating with the laser. The K-type thermocouple on the bottom of the bulk shape measures the temperature resulting from heat conduction through the thickness of the shape. Comparing these two curves in Figure 8, we see that for each perturbation in temperature at the top surface there is about a 100 second transient period at the bottom surface before steady state thermal conditions are reached. The corresponding emf histories from the two embedded thermocouples reflect these trends. There is a slightly longer transient period tending toward a plateau after about 200 seconds. Also, the emf from the embedded thermocouple closer to the heated surface is higher than the second embedded thermocouple as expected. This research demonstrates the viability of embedding thermocouples in bulk shapes and using the response of these devices to monitor thermal conduction through the part.

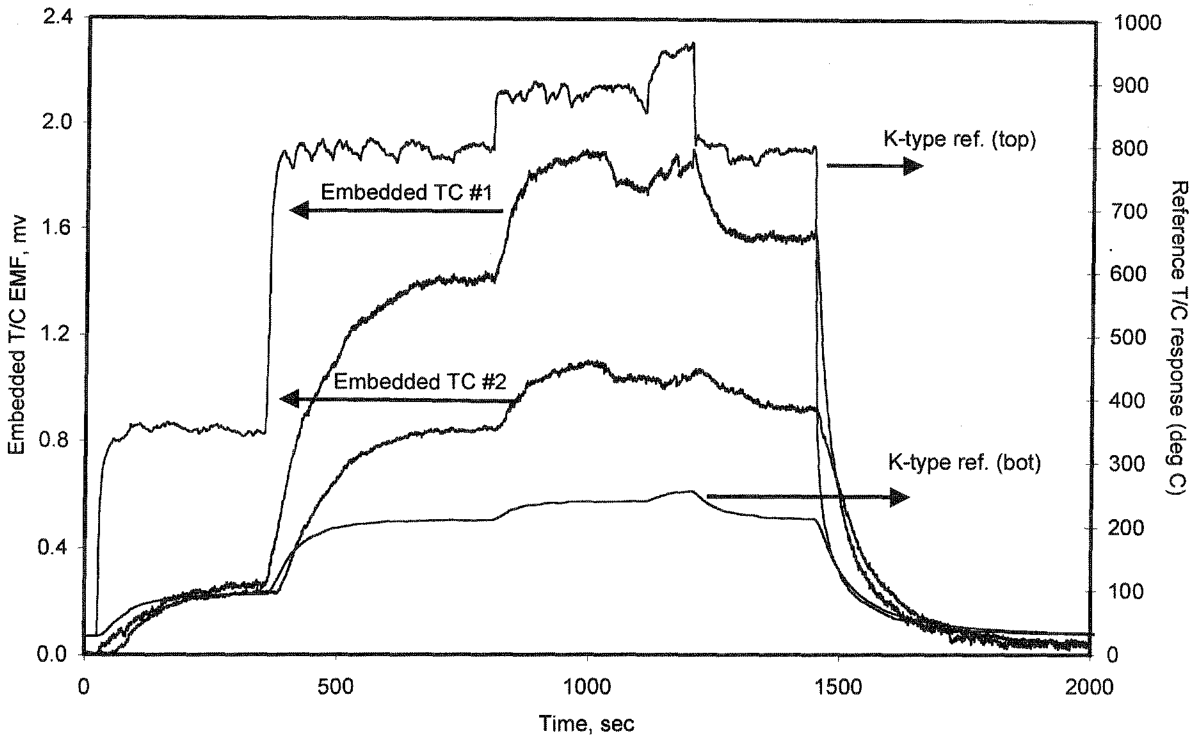

Figure 3. Response of embedded SiC/C thermocouples to an applied temperature history

Conclusions

A multiple layer bulk shape containing two thermocouples embedded at different internal locations has been fabricated using SALD and SALDVI. The thermal response of the embedded thermocouples matches that expected when a temperature gradient is applied to the bulk shape by surface heating. The viability of the proposed process has been demonstrated.

Acknowledgements

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