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The integration of optical interconnections on ceramic substrates

Bartlomiej Guzowski [a,*], Adam Rosowski [b,c], Zbigniew Lisik [a], Malgorzata Jakubowska [d], Martin Sharp [b]

[a] *Lodz University of Technology, Wolczanska 211/215, 90-924 Lodz, Poland*
[b] *General Engineering Research Institute, Liverpool John Moores University, GERI Building, Byrom Street, Liverpool L3 3AF, UK*
[c] *SPI Lasers UK Ltd., 3 Wellington Park, Tollbar Way, Hedge End, Southampton, Hampshire SO30 2QU, UK*
[d] *WARSAW University of Technology, Sw. Andrzeja Boboli 8, 02-525 Warsaw, Poland*

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ABSTRACT

High heat conductivity and high heat capacity make ceramic substrates indispensable to the manufacture of Multi-Chip Modules (MCM) and power electronics. In this paper a detailed description of the integration process of optical lines on to ceramic substrates is presented. The manufacturing of microgrooves in ceramic substrates and the process of integration of optical fibres and active elements is described. Coupling active elements to optical fibre is also presented. Through such an integrated optical line a 4 Gbps signal was transmitted.

1. Introduction

Many people believe that replacing electrical cables with optical fibres will solve many of the problems associated with the transmission of signals with GHz frequencies. This is reflected in the number of articles [1–4] and books concerning the introduction of optical interconnects into VLSI circuits [5–8]. The optical connections found in Integrated Systems (IS) divide into two groups: on-chip and off-chip. Many research programmes involved in the development of optical interconnections began at the end of the twentieth century [9,10]. These programmes focused on the development of optical technology in both systems for use with Multi-Chip Module (MCM), Printed Circuit Board (PCB) and between the modules found inside the computers. Optical systems can communicate with each other in free space [11]. Such systems have the advantage that they allow very high packing density and also by using a controllable micro-mirror, to switch light beams [12]. Unfortunately, a significant disadvantage of such free space communication is the difficulty in coupling entire optical systems [13]. Another option is to transmit signals through plastic optical fibres [14] or planar waveguides [15,16]. Within the work carried out by six Japanese research centres [17] scientists integrated on to a 4.5 mm × 5 mm silicon substrate thirteen optical devices which included InGaAsP laser diodes, Mach–Zehnder modulators, multimode interference (MMI) splitters, silicon rib waveguides and a PIN type Ge diode. The system has achieved transmission rates of 5 Gbps at a Bit Error Rate (BER) of less than 10^{-12}. Another solution was presented by researchers from the University of Cambridge [18], who realized, on a PCB, a demonstrator containing two layers of connections. On the upper surface of the substrate active elements (VCSEL, PIN photodiode made of GaAs, TIA amplifier) and multimode polymer optical fibre were distributed. On the bottom surface of the substrate metallic tracks and a layer of electrical connections were placed. The total power losses occurring in the optical path according to the authors reached approximately 8 dB with a transmission of 10 Gbps.

This paper presents the design process and realization of integration of optical interconnections on ceramic substrates. The multi-mode, bend-insensitive OM4 class optical fibre, described in the TIA 492AAAD standard, was chosen during the initial research [19]. The integration of the multi-mode optical fibre (MMF) as well as active elements (VCSEL and PIN diode) with ceramic substrates is also presented. Additionally the coupling of MMF to active elements by using angled ball-lensed optical fibre (ABLOF) is demonstrated.

2. Preparation of ceramic substrates for integration with optical interconnections

Ceramic substrates are used in the IS, thanks to their advantages such as: excellent mechanical and electroconductivity properties or relatively high thermal conductivity. Moreover they have similar thermal

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* Corresponding author.
E-mail address: bartlomiej.guzowski@p.lodz.pl (B. Guzowski).

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Table 1
The parameters of ceramic substrates used in electronics.

Parameter	Ceramic types				
	96% Al_2O_3	99,5% Al_2O_3	99% BeO	AlN	BeO/SiC
Density [g/cm^3]	3.7	3.9	2.9	3.3	3.2
Coefficient of thermal expansion [ppm/K]	6.4	6.6	5.0	5.6	
Thermal conductivity [W/mK]	35	37	250	170	270
Flexural strength [MPa]	220.8	338.1	131.1	300	
Dielectric strength [kV/mm]	8	9	14	20	
Specific resistance x 10^{14} (at 25 °C) [Ωcm]	7	7	10	10	>0.1

expansion coefficients to other common elements. A review of substrates commonly used in IS and their properties are shown in Table 1. Among ceramic substrates, the cheapest and most common substrates are based on aluminium oxide (Al_2O_3). Aluminium nitride (AlN) substrates are used for more advanced MCM modules, and power electronics, and the remaining substrates are used less frequently due to the high price, and in the case of beryllium oxide (BeO) the toxicity of beryllium.

3. Selection of ceramic substrates

It is believed that the new generation of electronic packaging requires excellent thermal stability and heat dissipation to achieve maximum performance. Therefore our goal was the realization of ceramic substrates, dedicated to MCM or Power Integrated Circuits (PIC) that have an integrated optical line. AlN and Al_2O_3 substrate materials have been widely used in high power module applications due to their high current capability, high heat dissipation, flexible patterning and high reliability [20,21]. The popularity and excellent performance mentioned above informed the decision to choose AlN and Al_2O_3 substrates in our research. Both substrates dimensions were 50 mm × 50 mm × 1 mm. For both these substrates integrated optical lines were made according to the design in Fig. 1. It is assumed that the height and the width of the microgroove were 280 μm, to enable to integrate optical fibre with primary coating (diameter 250 μm).

4. Manufacturing of the microgrooves in the ceramic substrates

The substrates are fairly difficult to process using typical grinding techniques due to their very high hardness and brittleness, especially in the micro-scale [22,23]. Chemical etching is found to be ineffective [24,25]. In this work, laser direct microprocessing was used to manufacture microgrooves in the Al_2O_3 and AlN ceramic substrates as an established technique to process ceramics [22,23,26,27]. All processing was performed using a 20 W G4 EP-Z SPI laser. The laser specifications are:

- Wavelength: 1604 nm;
- Maximum average power: 20 W;
- Beam quality: single mode, $M^2 < 1.6$;
- Pulse duration: 3 ns–500 ns is 5 ns steps; and
- Frequency: 1 kHz–1 MHz (depending on pulse duration).

The laser was connected to a GSI lightning galvanometer scanner head and a 100 mm F-Theta focussing lens was used to focus the laser beam (Fig. 2). The focused spot size is 29 μm. The laser allows the changing of the laser process parameters, including pulse durations, 'on-the-fly' during the machining process.

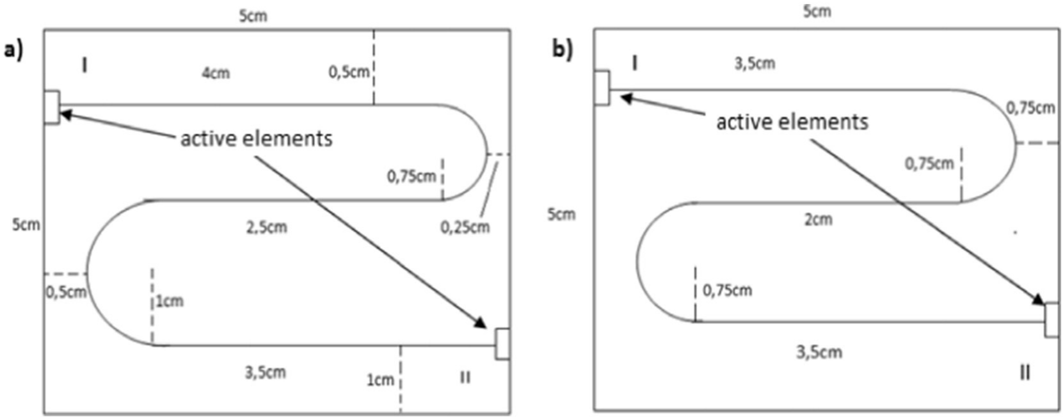

Fig. 1. Plan of ceramic substrates with: (a) asymmetric turns, and (b) symmetric turns.

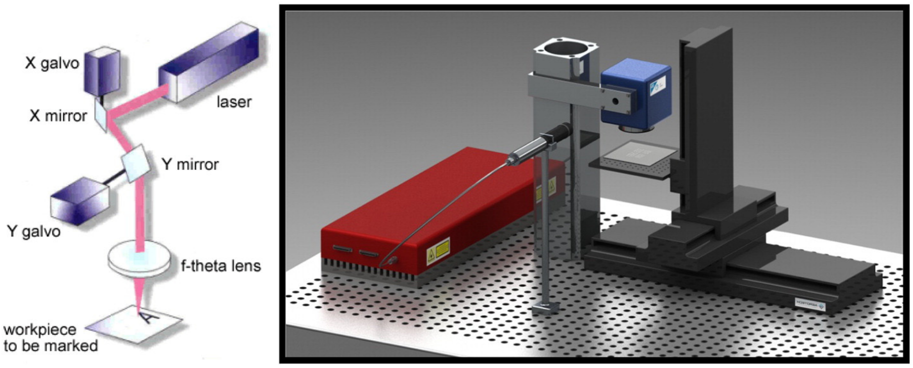

Fig. 2. The laser setup.