3D Printed Microplatform for Fiber-Coupled Optical Microsystems

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Abstract— **In this paper, a 3D printed microplatform for realization of fiber- coupling between a light source and an optical microsystems is proposed. The micro-platform is designed in a CAD software and printed using additive manufacturing fusing technology. The performance of the proposed microplatform is tested successfully by coupling an integrated CMOS photodiode with an area of $500 \times 500 \mu m^2$ to a pig tail laser that is attached to a $62.5\mu m/125\ \mu m$ multimode fiber optic cable. Experiment results show that the proposed microplatform presents a cost-effective alternative to the silicon-processed microplatforms.**

Keywords: Microplatform, 3D printed technology, Optical microsystems, Optical fiber transmission, CMOS photodiode, fiber coupling.

I. INTRODUCTION

Recent studies show that low power, compact, implantable, wireless biomedical microsystems are feasible due to the advances in micromachining and manufacturing processes [1]–[4]. Moreover, the proposed microsystems can be implanted and utilized for health monitoring and they can perform interventions without affecting the daily life of the patient [4], [5].

The major challenge for implantable biomedical microsystems is providing a continuous communication and energy to the system in safe and cost-effective means. There are various methods for providing energy to such microsystems; (1) compact batteries can be used [6], (2) the energy can be harvested from surrounding sources such as RF sources [7], mechanical movements [8], or thermal energy sources [4], (3) energy can be provided via wires [9], (4) lastly energy can be provided optically via fiber optical cables [10], [11]. The optical power delivery method has some advantages over the other power delivery methods; optical power delivery doesn't require a large antenna that is present in the RF systems, and, since the fiber optic cables are non-conductive, they can be used in the MRI environment [10], [12]. Specifically, in MRI environment, optical powering over fiber optical cables is safer, since conducting materials can cause damage to the nearby tissue by excessive heating during operations performed [10], [12]. However, for delivering power to the microsystems via fiber optical cables, the microsystem must be coupled to the fiber-optical cables. Generally this process is realized using silicon processed microplatforms [13] that can be implemented in a clean room environment. In order to realize a specific pattern and platform on the silicon material, a silicon wafer with a specific crystal orientation and related special tools and methods (e.g. wet etching, e-beam etc.) must be utilized. Hence, there is a practical limit in silicon process for achieving custom microplatforms.

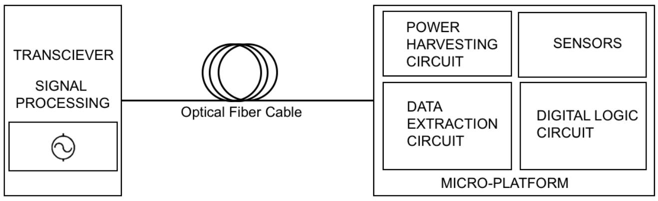

Fig. 1. Block diagram of a fiber-coupled all optical programmable biomedical system

3D printing technique provides important advantages such as offering low cost fabrication and fast prototyping. With high resolution systems, it presents an alternative to the silicon-processing for implementing biomedical applications. It has been demonstrated that high-complexity microstructures for biomedical applications can be manufactured at a much lower cost with a faster development time with 3D printing technology [14]–[16].

In this work, a cost effective 3D printed microplatform for fiber-coupled microsystems is presented. The platform provides efficient fiber optical coupling while providing high performance with minimal efficiency loss. The presented micro-platform is specially designed for integrated optically powered micro-systems that employ an on-chip CMOS photodiode. The platform can quickly be adapted any fiber coupling requirements.

The rest of the paper is organized as follows; the operation of the system is explained and the description of the blocks are given in Section II, fabrication steps and experimental results are presented in Section III, and lastly, the conclusions are presented in Section IV.

II. SYSTEM DESCRIPTION

Fig. 1 shows a general block diagram of a fiber-coupled all optical programmable biomedical system that can be employed in MRI environment. The system consists of two main blocks; The first block is a transceiver/signal processing unit that generates signals and processes the received signals. This block contains a light source for generating optical signals that are transmitted via a fiber optical cable to the second block which is an *In-vivo* integrated circuit that consists of sensing and programmable logic circuits. The microsystem can sense the surrounding data related to the patient health (e.g. temperature, resistivity, pressure etc.) and can send this data to the external block for signal processing. The communication between blocks is optically carried out through fiber optical cables.

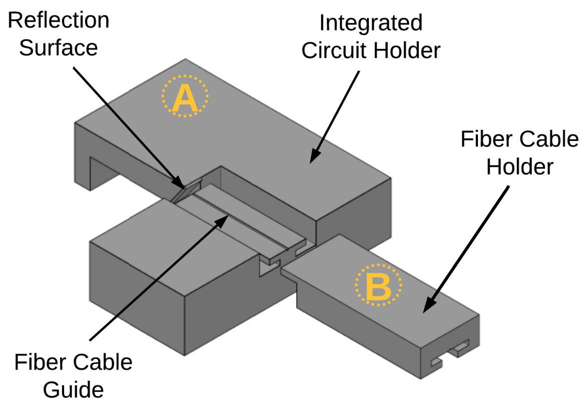

Fig. 2. CAD drawing of the proposed micro-platform structure designed for coupling 62.5μm/125μm multimode fiber cable to a CLCC44 package integrated circuit

The fiber coupling is realized through specifically designed 3D printed mico-platform shown in Fig. 2. The micro-platform consists of two main structures; The first structure is an integrated circuit holder which is denoted as "A" in Fig. 2 and a fiber optical cable holder which is denoted as "B" in Fig. 2. The integrated circuit holder contains an inclined surface that is designed for reflecting the output light of the fiber cable in the holder to the light sensitive area on the integrated circuit. The inclined surface is formed at an angle of 54.7° for performing a comparison between KOH silicon etching that also results a 54.7° angle from the plane. The integrated circuit holder also contains a V-shaped groove that serves as a fiber cable guide. The groove is created according to dimensions of the selected fiber. In the experiments a multimode fiber with a core-diameter of 62.5μm and cladding diameter of 125μm is utilized. The external jacket of the multimode fiber cable is removed and the remaining core and the cladding part of the fiber optical cable is placed into the V-groove, thus the V-groove width is selected to be greater than 125 μm in the surface.

Since the micro platform is placed on the integrated circuit, a hole shown in Fig. 3 is formed on the platform for allowing the laser light reach on to the light sensitive area on the integrated circuit. In order to increase the reflection properties of the 3D printed surface, the surface is covered by a reflective marker. The inclined surface acts as a mirror after this process. The integrated circuit holder is specifically designed for CLCC44 package which is used in the experiments. The platform covers and fits the entire chip package.

The second structure in the platform is a fiber holder which acts as a cover for the fiber optical cable and prevents vertical movement of the fiber cable placed inside the V-groove. The fiber cable holder is also attached and locked to the integrated circuit holder using L-shaped sliding guides present on both structures.

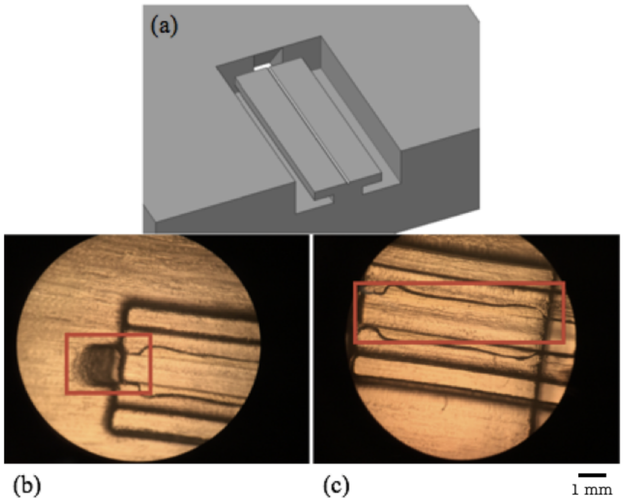

Fig. 3. a) CAD drawing of the hole located at the end of the V-groove and b) micrograph of the hole and c) micrograph of the V-groove after fabrication.

The microplatform also blocks the environmental light sources that can act as interfering noise sources for the optical integrated circuit placed inside and hence, the proposed microplatform increases SNR value for optical signal processing applications. Furthermore, independent from the environment luminosity, the energy delivery can be performed intermittently for applications which utilize controlled optical powering scheme where the operation of the system is controlled remotely [10].

III. EXPERIMENTAL RESULTS

The micro platform is designed in AutoCAD software, and fabricated using polymer material on OBJET Eden 260V high resolution 3D printer. The 3D printer provides approximately 100 μm printing resolution in the vertical direction and 15 μm printing resolution in the horizontal direction. The micro-platform has dimensions of $18\times18\times11\text{mm}^3$. The printed microplatform is also covered with adhesive tape for increasing light isolation. Fig. 4 shows the performed angle measurement of the printed reflection surface in ImageJ software. The angle of the reflection surface on the fabricated platform is measured as 54.15° which is 98.9% close to the desired value of 54.7°. The measurements show that the 3D printed microplatform has a very close angle value with a KOH etched silicon processed counterparts. The inclined surface of the manufactured micro-platform is then coated with reflective marker for increasing the reflectivity of the polymer material.

Fig. 5 shows integration of the proposed 3D printed and assembled platform to an optically powered CMOS integrated circuit that is inside of CLCC44 package. The CMOS integrated circuit employs a $500\times500\mu\text{m}^2$ on-chip

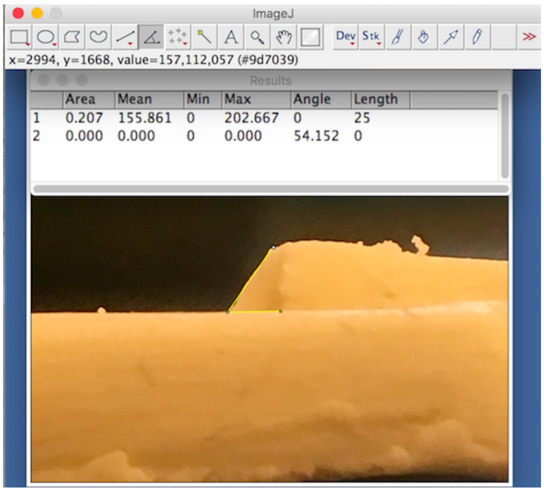

Fig. 4. The angle of reflective surface measurement in ImageJ software

integrated CMOS photodiode for optical communication. The transparent VeroClear polymer material used in printing process for confirming and demonstrating the alignment of the 3D printed structure.

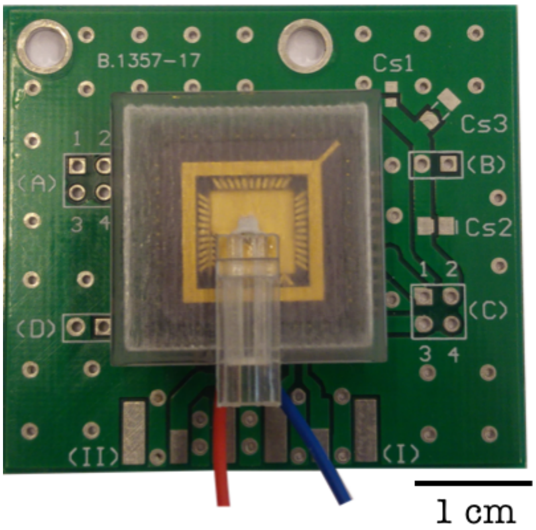

Fig. 5. Integration of the 3D printed platform to the optically powered CMOS integrated circuit. Transparent polymer material used in printing process for demonstration purposes.

Experiments are carried out to measure the transmission efficiency and the frequency response of the fiber coupled integrated microsystem. In the experiments, an ST fiber connector coupled laser diode (OPV314AT) with the center wavelength of 850 nm is used as the light source. 850 nm wavelength is selected considering the responsitivity and conversion efficiency of the integrated CMOS photodiode. The laser source consumes 7mA at forward voltage values of 2V. An ST connector coupled 62.5μm/125μm multimode pigtail fiber cable is also chosen for the coupling process. The laser source is attached to the pig tail fiber cable. The laser source then is driven with a square wave signal using a function generator. The frequency value of the square wave signal is swept from 0-5kHz range to measure the frequency response of the integrated system. The amplitude of the induced signal on the integrated CMOS photodiode is observed on an oscilloscope. The experimental results are shown in Fig. 6. The results show that the bandwidth of the overall microsystem is 360 Hz.

In the second experiment the optical power transmission is tested. In the experiment, the laser diode is coupled to a PM100D Thorlabs Optical Power Meter using proposed 3D printed microplatform on anoptical table. Forward laser diode voltage is swept from 1.6V to 2.2V. The power transmission experiment results are given in Fig. 7. The overall optical coupling efficiency is measured as 4.7%.

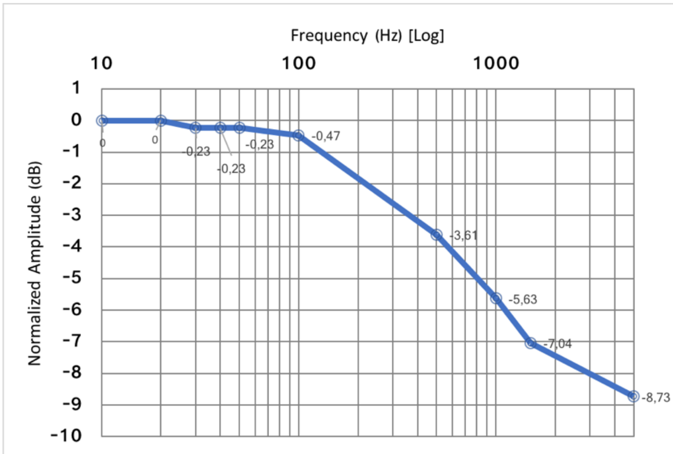

Fig. 6. Frequency response of the fiber-coupled integrated system that utilizes presented microplatform

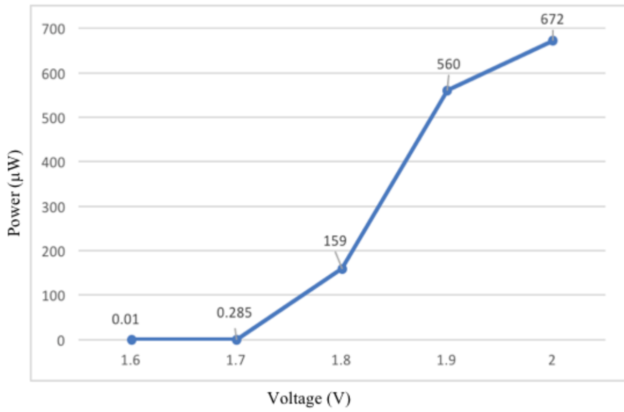

Fig. 7. Power transmission of the proposed fiber coupled microsystem at forward laser diode voltage values between 1.6V and 2.2V.

IV. CONCLUSIONS

In this paper, a 3D printed microplatform for realization of fiber- coupling between a light source and an optical microsystems is proposed. The micro-platform is designed in a CAD software and printed using additive manufacturing fusing technology. The performance of the proposed microplatform is tested by successfully coupling an integrated

$500 \times 500 \mu m^2$ CMOS photodiode to a pig tail laser that is attached to a $62.5 \mu m/125$ μm multimode fiber optic cable. Frequency response and the power transmission experiments are carried our successfully. The experiment results show that the proposed microplatform presents a cost-effective alternative to the silicon-processed microplatforms.

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