Chapter 34
Fiber Optic Broadband Ultrasonic Probe for Virtual Biopsy: Technological Solutions

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Abstract An ultrasonic probe was developed by using, in conjunction, opto-acoustic and acousto-optic devices based on fiber optic technology. A Micro-Opto-Mechanical-System (MOMS) approach is proposed to realize the broadband ultrasonic probe on micromachined silicon frames suited to be mounted on the tip of optical fibers.

34.1 Introduction

Our group proposed the design and realization of an ultrasonic source based on opto-acoustic effect in 1996, with a metal layer over the fiber optic tip as absorbing target [1]. In 2001 we improved, of about two orders of magnitude, the opto-acoustic conversion by replacing the metal absorbing target with a graphite one [2]. The transmitting element, depicted in Fig. 34.1a, is constituted by a fiber optic on whose tip an absorbing layer is deposed; Thermo-elastic Ultrasound Generation (TUG) takes place when the laser pulse hits this absorbing thin layer and the induced thermal expansion generates a mechanical shock wave.

The receiving element is constituted by an extrinsic fiber hydrophone, based on a Fabry–Perot interferometer, as depicted in Fig. 34.1b. A continuous wave laser

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G. Neri et al. (eds.), *Sensors and Microsystems*,
Lecture Notes in Electrical Engineering 91, DOI: 10.1007/978-94-007-1324-6_34,

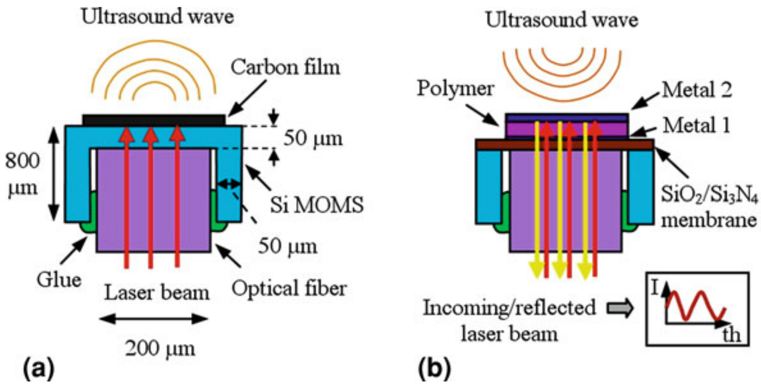

Fig. 34.1 MOMS opto-acoustic transmitter (**a**) and receiver (**b**) mounted on an optical fiber

beam is launched inside a fiber. The device works as follows: a pressure wave, impinging over the interferometer, modulates its thickness. This change in thickness produces a modification in the interferometer reflectance, defined as the ratio between the reflected and incident light power, and thus induces a change in the light intensity detected by a photodiode. For the proposed probe, completely based on a fiber optic technology, a strong miniaturization can be obtained, making it suitable for intravascular, endoluminal and percutaneous applications. In 2006 the first ultrasonic images obtained with a fully fiber optic ultrasonic probe were presented [4].

34.2 Technological Solutions and Measurements

In both devices, micromachined silicon MOMS (Micro Opto Mechanical Systems) are used to permit the housing of the optical fiber close to the optical layers used for ultrasound emission and detection. For the transmitting element a carbon film with high optical absorption is deposited and patterned on the MOMS upper surface.

For the receiver, a planar Fabry–Perot interferometer is realized on a dielectric membrane (SiO_2/Si_3N_4) obtained, on the silicon substrate, by backside etching. The interferometer is constituted by a polymer spacer with a low elastic modulus, so that its thickness can be modulated by an incoming ultrasound wave. For the carbon layers, photoresist carbonization on silicon has been investigated as a fabrication technique, using OIR 908-35 positive photoresist from Fujifilm. The technological process, reported in Fig. 34.2a, has been adopted to realize some prototype samples. Starting from 500 μm thick <100> oriented silicon substrates, a thermal oxidation step has been carried out at 1,000°C in wet environment, yielding a roughly 500 nm thick silicon oxide layer on both sides of the wafer (step 2). This layer has been used as a mask for the subsequent silicon micromachining (step 4), after backside patterning and etching with Buffered

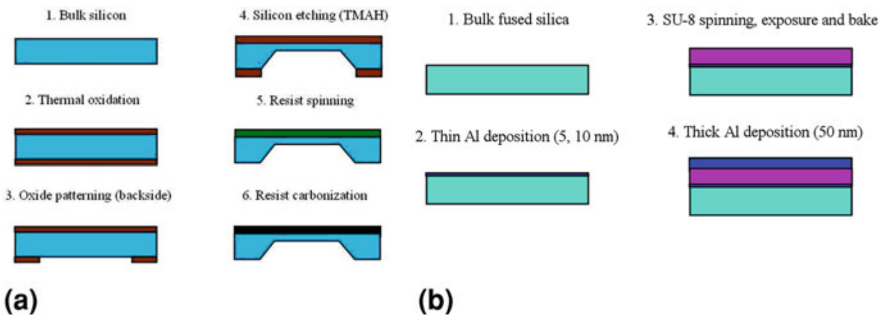

Fig. 34.2 Technological process used to realize carbon layers (**a**) and planar Fabry–Perot interferometers (**b**) on fused silica substrates

Oxide Etch (BOE, step 3). In this way, square silicon membranes with thickness around 200 μm and area of 1 × 1 mm^2 have been obtained on the wafer. After removing the SiO_2 mask, OIR 908-35 photoresist has been spinned on the wafer front side at 3,000 rpm, yielding a roughly 4 μm thick film. The resist layer has been subsequently carbonized by means of an annealing step performed at 750°C in argon atmosphere for 30 min. With the same procedure, carbon layers have also been realized on double-side polished wafers for the optical measurements. It has been observed that the carbon layer obtained after carbonization is roughly 1 μm thick, as a result of volume shrinking of the starting resist layer. For the detector, negative resist SU-8 has been chosen to fabricate the polymer spacer. For the preliminary tests, planar Fabry–Perot interferometers with different thicknesses of the spacer and of the thinnest metal film have been realized on fused silica substrates (pure SiO_2) according to the process flow of Fig. 34.2b. Fused silica has been chosen to mimic the optical properties of the SiO_2/Si_3N_4 membrane that is expected to be adopted in the detectors. Aluminum has been deposited by evaporation to realize both the thin and the thick metal layers of the interferometers. The thickest layer was 50 nm thick, while two thicknesses have been tested for the thinnest one (5 and 10 nm). SU-8 has been deposited by spinning, in 5 and 10 μm thick layers, obtained by varying the spinning speed. The resist layers were exposed to UV light and hard baked at 200°C for 5 min on a hotplate before depositing the last Al layer (50 nm).

The carbon layers on silicon and the Fabry–Perot interferometers on fused silica have been subjected to optical and acoustic characterizations. The optical transmittance of carbon layers obtained on double-side polished 500 μm thick silicon substrates has been measured with a Nicolet 5700 Fourier Transform Infrared (FTIR) spectrometer and compared with the one of a plain silicon wafer (Fig. 34.3a). The measurement shows an evident decrease of the silicon wafer transmittance in the near IR range due to the presence of the heavily absorbing carbon film.

The reflectance of the Fabry–Perot interferometers realized on fused silica has been also measured both in the optical and IR range. In Fig. 34.3b, the results of

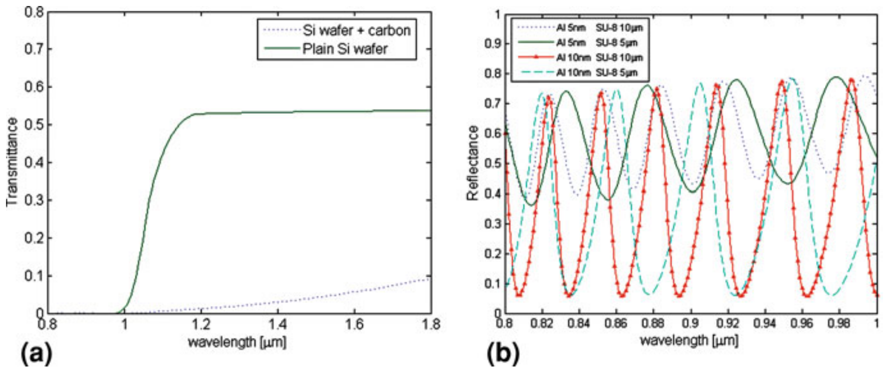

Fig. 34.3 **a** NIR transmittance of a carbon layer on a double-side polished silicon wafer compared with the one of a plain silicon wafer. **b** NIR reflectance of planar interferometers realized with different thicknesses of the SU-8 spacer and of the thin Al layer

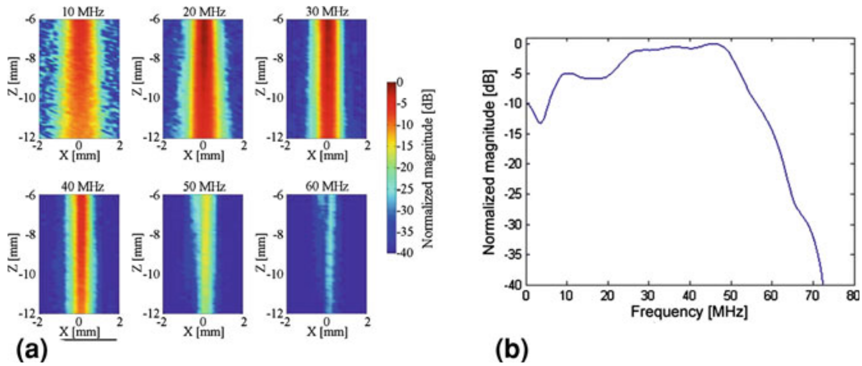

Fig. 34.4 **a** Magnitude of acoustic field longitudinal section, filtered at six different frequencies. **b** Spectral response of the MOMS fiber optic probe

the optical characterizations performed in the visible and NIR range on interferometers with different thickness features are summarized.

A longitudinal section of the acoustic field, generated by the opto-acoustic transmitter, was acquired by employing a PVDF membrane hydrophone (Marconi 699/1/00002/200). In Fig. 34.4a, the magnitude of the acoustic field filtered at six different frequencies is reported for 6–12 mm distance from the transducer. The colormap represents the same magnitude level for the all six pictures. The decrease in magnitude observed for high frequencies range is partially due to the hydrophone frequency response (60 MHz cut-off).

The global response of the MOMS fiber optic probe has been obtained by facing the transmitter and receiver elements with each other and acquiring the ultrasonic signal. In Fig. 34.4b the spectral response of the probe is reported.

34.3 Conclusions

Preliminary results are presented on the opto-acoustic emission properties of carbon films (thickness around 1 μm) and about the optical and acoustic behaviour of planar Fabry–Perot interferometers composed by thin metal layers and SU-8 negative photoresist on fused silica substrates.

The high frequencies and large bandwidth in conjunction with the extreme miniaturization derived from the MOMS technology could open a way towards "virtual biopsy", intended as the possibility for studying and characterizing the nature and health conditions of living tissues "in situ".

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