Technological development of THz microfluidic microsystems for biological spectroscopy

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Abstract

We investigate a possible fabrication of microfluidic MEMS dedicated to the THz spectroscopy in a mixing technology based on silicon substrate coated with a thick layer of polymer. This layer is useful for the microfluidic circulation and the electromagnetic propagation. We use an original deposition process realized by RPECVD (Remote Plasma Enhanced Vapor Deposition), called also "cold plasma". We obtain layers up to 110µm without any cracks. We have measured the dielectric characteristics of this new type of polymer up to 220 GHz with a vectorial network analyzer and between 0.1 to 1.2 THz in the time domain with an electro-optic technique. This technology is now ready and allows realizing a mass production compatible with disposable bioMEMS.

Introduction

An important development of biosensors towards bioMEMS is in progress, in particular, with microfluidic facilities. Generally, the transduction function is realized by an electrochemical way but some new physical measurements such as in the optical domain, give good results. On the other hand, interesting measurements are obtained on THz spectroscopy of biomolecules, but in free-space measurement or on dry matter [1-2]. Few measurements are available on biomolecule in solutions. Note that these solutions are aqueous or not. For example, a new enzymology develops around the organic liquids more favorable in the THz frequencies. The combination between very small investigation volumes and integrated THz probe could bring new interesting results.
The design of such microfluidic bioMEMS should answer to a good microfluidic and electromagnetic propagation, and should have an antiseptic character. We have selected to use a mixed technology polymer on silicon where the polymer is laid down by a "cold" RPECVD technique [3]. We present here the propagation and dielectric characteristics of this very original polymer, well fitted for a future mass production.

Perspective in biology

The measurement will be led in an enzymology laboratory on the analysis of a hydrolysis reaction. Three types of proteins could be used: a homogeneous large protein such as albumin, a large protein constituted by four parts such as hemoglobin, and a small protein such as the lysosym. We'll follow the signal evolution with the hydrolysis progress. The design of the complete microsystem can be presented in figure 1. A upper stage is dedicated to the biological reaction. The fluid goes through holes to the lower stage dedicated to the measurements.

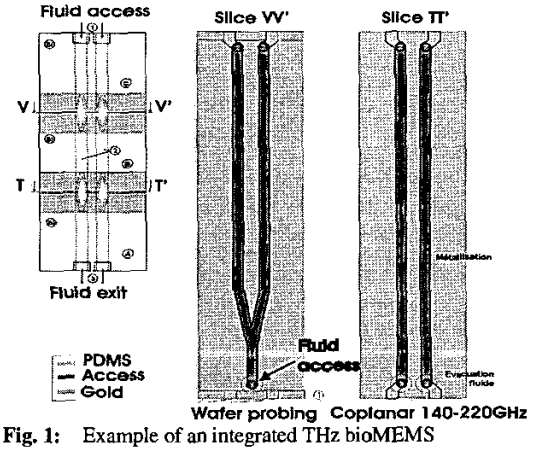

Fig. 1: Example of an integrated THz bioMEMS

Microfabrication technique

Many microfluidic MEMS have been developed on silicon with a third dimension realized by a bounding of glass or silicon. This technique involves a high temperature and a high voltage levels giving only a global functionalization possibility. In the other hand, there is a great development of all polymer microfluidic MEMS, but in this way, it is difficult to put the source and detector components on the microsystem.
We have selected to combine silicon and polymer. Different techniques are used which are embossing, molding, laser photoablation and more recently, some techniques coming from the microelectronic processes using photosensitive resins such as SU8, PDMS, BCB. But these last answers are not entirely satisfactory.
Polymer films are widely used but also promising in microelectronics for design of low-k interlayer dielectrics. Good adhesion, low stress, good hardness and low surface roughness are required in addition to good dielectric behavior. Plasma techniques are one of the ways to produce such films. Basic Plasma Enhanced Chemical Vapor Deposition processes i.e. low pressure systems, allow to produce good quality film but for low or moderate thicknesses because of quite small growth deposition rates. The present purpose is to obtain dielectric layers with thicknesses as large as 50 µm within reasonable times. The present route to lay down a polymer by use of plasma assisted polymerization technique based on a Microwave Induced Remote Afterglow. The monomer that we use is a TMDS (Tetra-Dimethyl-Di-Siloxane) and create a layer of pTMDS (plasma polymerised TMDS).

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Results

We have investigated the capability of our polymer to give a good electromagnetic propagation. We have designed coplanar waveguides and striplines deposited on a 50 µm layer of pTMDS. The transmission lines are realized by a gold layer deposition of 1 µm on a titanium binding layer of 500 Å by evaporation. We use a classical microelectronic technique (resin, mask, UV exposure, plasma etching to remove metal and binding layer) for the design of the lines. Two measurement methods have been employed.

A first method uses a Vectorial Network Analyser (VNA) Anritsu 37147C working in the bandwidth 140-220 GHz. It is associated with mixers of reference V05VNA2-T/R from OML (Oleson Microwave Laboratories). We use LRM calibration with a calibration kit reference 101-190B of Cascade Microtech. The analyzer is gauged in the plane of the measurement probes.

The second method is a temporal measurement using a $Ti:Al_2O_3$ femtosecond laser. It is based on electroabsorption sampling [4]. LT-GaAs and LT-AlGaAs layers are bonded on the coplanar striplines. These materials are respectively used to generate a sub-picosecond electrical pulse and to sample the electric field after propagation.

From the scattering parameter measurements, we can calculate the chain matrix which depends on the characteristic impedance Zc, the propagation constant γ, and the length l of the coplanar line. Starting with the matrix chains, we determine the parameters of the coplanar line Zc and γ. We apply a quasi-TEM model where the distributed parameters are computed as an equivalent circuit (RLCG). Indeed, this model takes into account losses in the central taper and in the dielectric. The computation of the ratio $\frac{\gamma}{Zc} = G + jC\omega$ allows determining the linear conductance and capacitance of the line. We extract the relative complex permittivity of the polymer from G and C values by the expressions established by Heinrich [4].

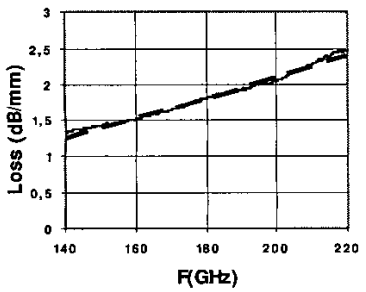

Fig. 2: Coplanar waveguide attenuation of the pTMDS

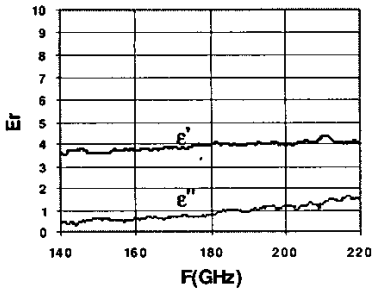

Fig. 3: Real and imaginary parts of the complex permittivity of the pTMDS

We give the results we have obtained between 140-220 GHz on a 50µm pTMDS layer deposited on a standard silicon wafer in figures 2 and 3. In figure 4 and 5, we show the results obtained up to 1 THz. Note that the results have a good correspondence in the 140-220 GHz frequency band.

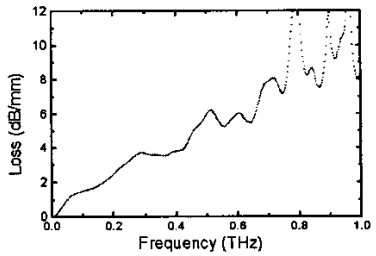

Fig. 4: Temporal measurement obtained with a stripline on pTMDS

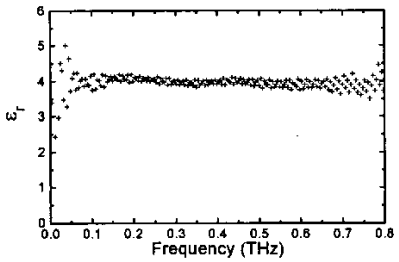

Fig.5: Temporal measurement obtained with a stripline on pTMDS

Conclusion

We have shown the results we have obtained on a new type of polymer processed by a "cold plasma" technique. This approach allows a very high compatibility with the microelectronic process and not only for biological applications. Note that the loss level is acceptable up to 220GHz, but remain high at 1THz. It is possible to change the different gaseous ratio of the deposition process to obtain a porous polymer structure, but not compatible with the microfluidic flowing. We move towards a multilayer process for combining this two approaches.

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