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A Zeolite-coated Silicon Wafer for Small Nucleic Acid Detection

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Extended Abstract

Several studies underline the fact that circulating small nucleic acids, such as microRNAs, are directly involved in many physiological and pathological processes, particularly in processes of cancer initiation and progression (Cortez et al, 2011). The involvement of miRNAs in tumourigenesis make them perfect non-invasive blood-based biomarkers for the early detection of cancer because of their great stability in tissue and body fluids such as plasma and serum (Schwarzenbach et al, 2014).

In this work we investigate the interaction between small nucleic acids and synthetic nanoporous zeolite with the aim of fabricating biosensors for cancer detection. A thin layer of zeolite was deposited onto a silicon wafer and the absorption of single-strand DNA molecules was studied through FTIR spectroscopy. Biosensors that interface a nanoporous zeolite thin-layer and silicon-integrated circuits can be fabricated to directly transduce biochemical signals into electrical signals (Fiorillo, 2012).

Zeolite is a nanoporous, crystalline aluminosilicate characterized by $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ tetrahedra linked to each other by an oxygen T-O-T bond, the pores and channels of which range from 3 Å to 20 Å in diameter (McCusker, Baerlocher, 2005). The zeolite structure, pore dimension, ion exchange capacity and the amount of Brønsted acid sites present make zeolite suitable for the absorption of biomolecules.

Other zeolite-based devices have been proposed in literature but they are not compatible with silicon-integrated microcircuit technology because of the high temperatures necessary for the process of calcination during the synthesis of the zeolite (450 C°). Our technique is based on direct spin-coating onto a silicon wafer of a mixture composed of 30% zeolite 3A powder and 70% natural vegetable oil w/w. The most suitable oil for the zeolite mixture is castor oil because of its chemical characteristics such as a low smoke point and low viscosity, which result in a reduced curing temperature and a more uniform layer (Fiorillo, Pullano, 2012). Following spin coating, the silicon wafer is annealed onto a hot plate at 120 C° overnight to obtain a thin and firmly adherent zeolite layer, ranging from 11 µm to 18 µm in thickness.

The SEM-microanalysis spectrum reveals, other than the standard chemical composition of zeolite 3A, only a very small number of carbon atoms originating from the heating process. The interaction of the zeolite structure and small nucleic acids was investigated by FTIR spectrometer equipped with a microscope. In the experiment, 5 µl of solution of single-strand DNA, characterized by 22 nucleotides (100 pmol/µl), was deposited through a tube onto the layer and then examined by IR microscopy after being washed in deionized water. Infrared analysis reveals that characteristic infrared oligonucleotide peaks such as 1160 cm^{-1} and 832 cm^{-1} appear in the zeolite infrared spectrum. The absorption site peaks of the zeolite framework are observed to be shifted in frequency of about 10 cm^{-1} due to the electrostatic- and Van Der Waals-interaction between the zeolite pores and the absorbed small nucleic acids.

The nanoporous characteristics of zeolite coupled with the deposition process of a thin-layer compatible with IC technology stand out as a promising, non-invasive device integrated onto a silicon wafer for use in small-scale biomolecule detection and could be implemented in biomedical engineering as an early diagnostic tool.

References

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