DOI 10.5162/EUROSENSORSXXXVI/PT4.200

Development of a novel silicon-based biocompatible EEG electrode

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Summary:

This paper presents a proof-of-concept silicon-based biocompatible dry/semi-dry platina EEG electrode prototype for future usage in BCI systems. Using silicon-based MEMS technology, varied topography can be created with dry and wet chemical milling. Other microtip-based electrodes achieve direct contact by penetrating the epidermis. Our approach is to increase the adheres and contact surface on hairy skin without penetrating into the skin surface.

Keywords: Electroencephalography, Electrodes, Brain-computer interfaces, Biomedical electrodes, Microelectromechanical

Introduction

There is increasing demand for applying the results of neuroscience and cognitive neuroscience in brain-machine interfaces in many interdisciplinary research areas. In recent decades, traditional conductive gels and silver/silver-chloride electrodes become less popular for electroencephalography (EEG) devices, and more convenient dry and semi-dry electrode systems have become commercially available. Their advantages are that they are more comfortable, gel dehydrates over time [1], and leave an unpleasant stain. However, dry and semi-dry electrode signal-noise ratio is usually lower than traditional wet EEG systems [1], [2]. As a result, these brain-machine interfaces often do not provide the expected performance.

This paper proposes a novel fabrication approach that integrates mechanical milling with a dicing saw and wet chemical etching, doping, and coating methods using semiconductor MEMS technology. The fabrication process begins with wet chemical etching of a 1000 µm thick silicon substrate. This way, the tips of the electrodes are formed. After that, mechanical milling is applied by a dicing saw to form square electrode geometries. Subsequently, the electrode material is further doped to achieve better electrical conductance. The platinum layer is deposited to the electrode surface in the last step to achieve sufficient electrode-skin contact.

The integration of Hybrid Mechanical Milling with Wet Chemical Etching processes in semiconductor MEMS technology enables the realization of intricate electrode designs with high precision and reproducibility.

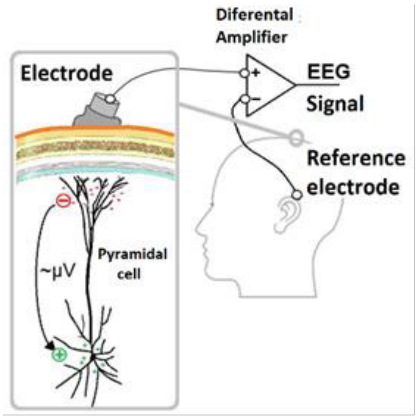

Fig. 1. The postsynaptic potential change of the pyramidal cells creates an electric dipole, the electric field measured by the EEG device.

Background, Motivation, and Objective

Our long-term vision is to develop a multisensory brain-computer interface (BCI) system for detecting students' stress, concentration, and arousal levels to evaluate different teaching methods. We intend to provide a tool for a more comprehensive understanding of students' cognitive and flow mental states by integrating multiple sensor systems, leading to the development of more effective teaching strategies and interventions that could ultimately improve educational outcomes. Currently, our focus is to improve the EEG recordings by experimenting with new electrodes and device structures to achieve a BCI system that can measure students' EEG during lessons quite comfortably.

Electrode manufacturing process

The electrode manufacturing process starts with a 1 mm thick, n-type phosphorous doped wafer with surface orientation of <100> and 1-2 Ωcm resistivity. The wafer is cleaned using the RCA1 and RCA2 standard processes. After that, a 200 nm thick oxide layer is grown on the surface by high-temperature dry oxidation to create a masking layer for the wet chemical etching. The pattern is created for the tips using a 400x400 µm rectangular mask in a 400x400 µm raster, as seen in Fig 2.

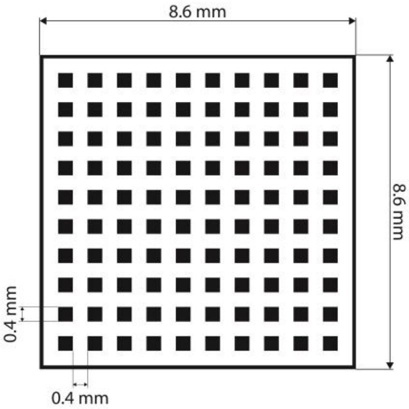

Fig. 2. Mask pattern for wet chemical etching.

The wet chemical etching is performed with 5wt% TMAH (Tetramethylammonium hydroxide) in purified H_2O for 80 minutes at 92°C to create an even D=100 µm deep anisotropic etching between the electrode tips. (Fig. 3.)

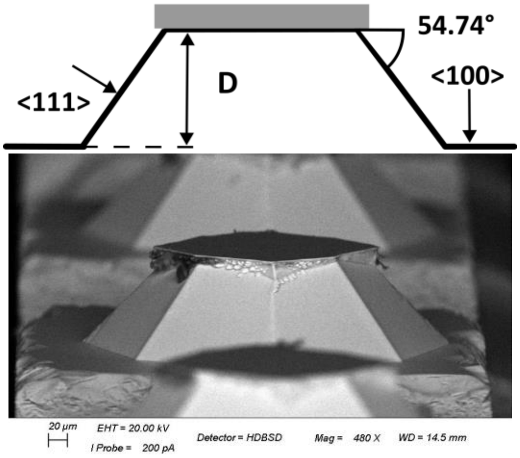

Fig.3. Electrode tips created by TMAH etching.

To create a homogenous etched surface and prevent the unwanted formation of micro pyramids 0.2 wt%/hour of APS (Ammonium Persulfate) was added to the solution.

The 400 µm deep ditches were created by a 300 µm thick dicing saw. (In the structure shown in Fig. 4., the staggered indentation is a by-product of the saw's geometry.) Hair can slip into the trenches, and in the future, we would like to experiment with filling them with skin conductance increasing materials.

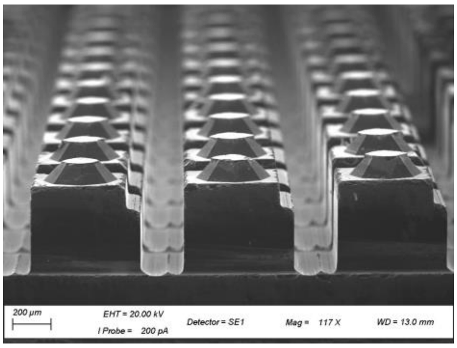

Fig. 4. Electrode structure.

To increase the conductivity of the silicon substrate, further doping with n-type phosphorus was performed to make the substrate highly doped near the surface. Finally, a ~100 nm platinum layer was sputtered on the electrode surface to increase the conductivity further and make it biocompatible and resistant to mechano-chemical effects. (Fig.5.)

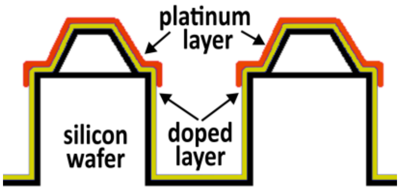

Fig. 5. Electrode final layer structure.

Results

This paper presented a platina-coated silicon-based dry EEG electrode prototype structure and its manufacturing process. The electrode's surface design adheres well to the skin's surface, even under slight pressure, without penetrating into its upper layers. The structure is sufficiently resistant and does not wear out during use. Further characterization and real-world EEG testing will proceed in the near future.

Acknowledgements

The research reported in this paper was fully funded by the K_20 grant through project No. 135224 of the National Research, Development and Innovation Office (NKFIH).

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