SPUTTERED TIN AND IrO_2 ELECTRODES VERSUS STANDARD AG/AGCL ELECTRODES FOR NON-INVASIVE EEG APPLICATIONS

J. H. Correia[1*], B. Wessling[2], N. S. Dias[1], H. R. Silva[1], W. Mokwa[2], U. Schnakenberg[2]
[1]Dept. Industrial Electronics, University of Minho, Campus Azurem,
4800-058 Guimaraes, Portugal
[2] IWE1, RWTH Aachen University, Sommerfeldstr. 24, D-52074 Aachen, Germany
[*]higino.correia@dei.uminho.pt

Abstract — *This paper presents the electrical performance and a comparison between different types of electrodes for application in EEG measurements. Sputtered TiN electrodes, standard sintered Ag/AgCl ring electrodes and sputtered IrO_2 electrodes were used in a braincap for monitoring the frontopolar position in patients according to the standard configuration 10-20 system. The experimental results show a better performance of the sputtered IrO_2 electrodes compared with the standard sintered Ag/AgCl ring electrodes. In all experiments electrolytic gel was used, but the results promise a new opportunity for the application of a dry IrO_2 electrode.*

Key Words: *Non-invasive EEG electrodes, sputtered IrO_2 electrodes*

I INTRODUCTION

Over the past century, research by neuroinvestigators (biomedical engineers and medical doctors) has provided us with a basic understanding of the organization of the brain and the biophysical properties of the neurons. Much of this understanding was obtained from single electrodes that record the electrical responses of these neurons to various stimuli [1].

The high demand on non-invasive EEG electrodes for monitoring, diagnostics and treatment of patients with neural diseases such as epilepsy is driving the research of electrodes fabricated in different materials and with very low impedance.

Data-acquisition systems for biomedical signals use electrodes for biopotential measurements. Standard sintered Ag/AgCl ring electrodes are frequently used for clinical and biomedical applications (e.g. ElectroCardioGraphy and ElectroEncephaloGraphy). These electrodes require skin preparation and use of electrolytic gel for reducing the impedance [2]. The electrodes for high quality recording of low amplitude biopotentials, such as for monitoring the brain activity in a non-invasive way (signals with an amplitude of few microVolt), must have very low impedance.

In this article, different types of materials for electrodes are tested in EEG: sputtered TiN electrodes, standard sintered Ag/AgCl ring electrodes and sputtered IrO_2 electrodes. The fabrication of the TiN and IrO_2 electrodes are described in detail. The neural electrodes are distributed in a braincap following the standard configuration 10-20 system of the International Federation in Electroencephalography and Clinical Neurophysiology.

Figure 1. Classic EEG braincap with the electrodes distributed in the standard configuration 10-20 system.

II ELECTRODE CONCEPT

II.1 SILVER/SILVER CLORIDE

Commercial sintered Ag/AgCl ring electrodes for guaranteeing low constant transition resistance were used in the measurements. This type of electrode is usually used in EEG sessions with patients.

II.2 SPUTTERED TITANIUM NITRIDE ELECTRODES

TiN was deposited by means of DC magnetron sputter deposition from a Ti target in an Ar/N_2 plasma. A Nordiko NS 2550 sputtering equipment was used for TiN deposition and the sputtering chamber was evacuated to at least $4x10^{-6}$ mbar by means of a cryogenic pump. A previous study of the nitrogen gas flow (between 0.6 sccm and 2.2 sccm) showed that for the same pumping speed (270 l/s) and a power of 500 W the lowest resistance is achieved with 0.8 sccm N_2 ($440x10^{-6}$ Ohm*cm at films with a thickness of 230 nm).

II.3 SPUTTERED IRIDIUM OXIDE ELECTRODES

Also IrO_2 was deposited by means of DC magnetron sputter deposition from a target in an Ar/O_2 plasma, prior to which a Ti adhesion layer (with a thickness of 50 nm) was deposited on the substrate. The oxygen gas flow was fixed at 1.85 sccm according to the procedure described in [3]. The IrO_2 resistance in a 270 nm thick film was $349x10^{-6}$ Ohm*cm (see Figure 2).

The film thicknesses were determined via lift-off process with a Tencor Pa-10 profilometer. The thin film resistance was measured in a classic 4-point probe system.

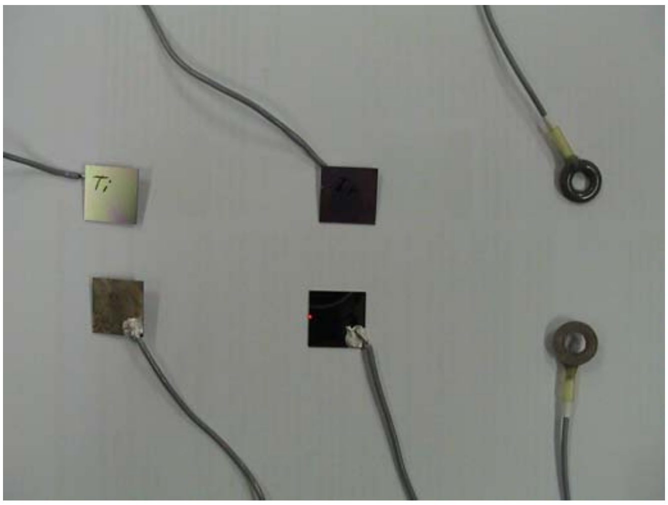

Figure 2. The fabricated/mounted electrodes in a set of pairs, from left to right: sputtered TiN electrodes, sputtered IrO_2 electrodes, and standard sintered Ag/AgCl ring electrodes.

III MEASUREMENT AND ANALYSIS

The data-acquisition system used in the experiments is composed of an amplifier with 40 channels and an A-to-D converter of 22-bits (sampling frequency at 2000 Hz), and a braincap with large filling holes and flat clip-on adapters making skin preparation and gel application simpler and improving preparation time. The amplifier is connected to a PC (via USB) that runs the recording software. The recording electrode was applied in the frontopolar area (in position FP2) in a standard configuration 10-20 system used in EEG clinical diagnostics and the other electrode of the pair was the reference (see Figure 3).

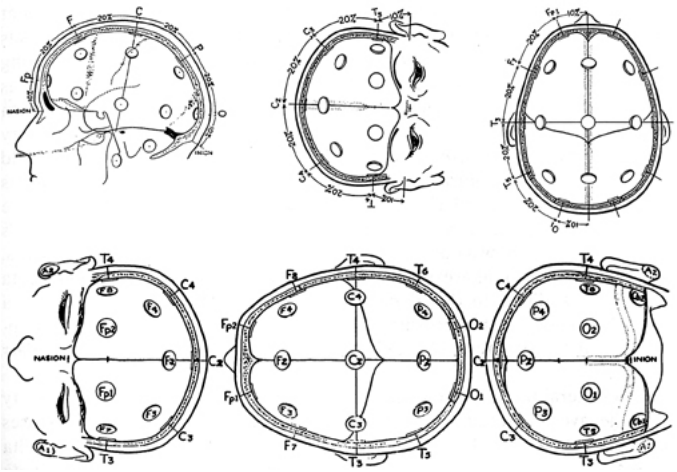

Figure 3. The 10-20 electrode system is recommended by the International Federation of EEG Societies. The left bottom image shows the position FP2 used in the measurements.

During the measurements the patients were in contemplation of a picture for trying to avoid the frequently blinking of the eyes during 3 minutes.

The study contemplated the extraction of the power of the signal in FP2 versus the frequency, using the Fast Fourier Transform in the range of interest, 0.5-30 Hz, for EEG (analyzing the Delta 0.5-3 Hz, Theta 3-7 Hz, Alpha 7-13 Hz and Beta 13-30 Hz waves). Figures 4 to 6 show the FFT response of the sputtered TiN electrodes, standard sintered Ag/AgCl ring electrodes and sputtered IrO_2 electrodes, respectively.

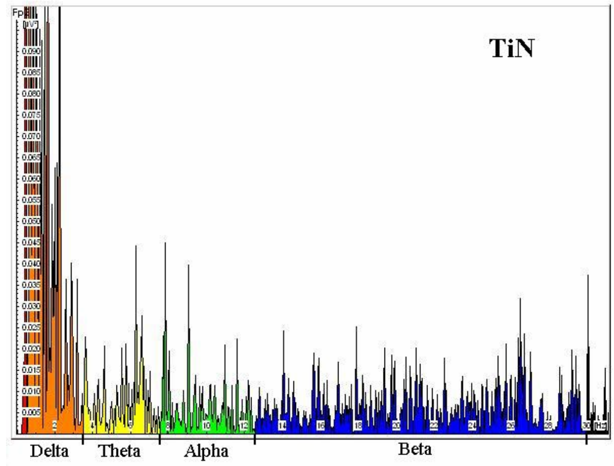

Figure 4. The FFT response of the sputtered TiN electrodes in terms of power (μV^2) versus frequency.

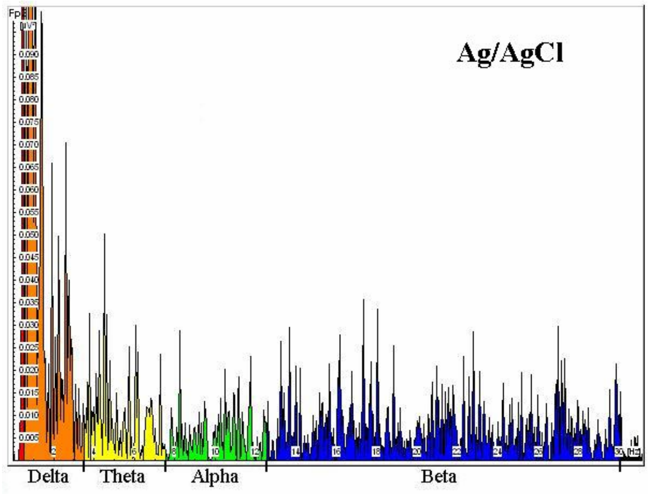

Figure 5. The FFT response of the standard sintered Ag/AgCl ring electrodes in terms of power (μV^2) versus frequency.

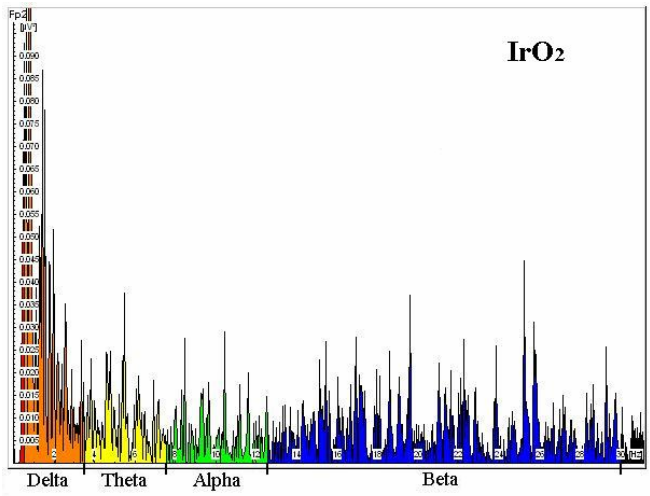

Figure 6. The FFT response of the fabricated sputtered IrO_2 electrodes in terms of power (μV^2) versus frequency.

The FFT response was obtained in terms of power of the signal (μV^2) versus the frequency.

The amplitude of the signal in average is higher for the IrO_2 electrodes (high-amplitude signals in sub-delta). Also, they have an excellent response in Theta and Beta waves compared to the standard sintered Ag/AgCl ring electrodes. The sputtered TiN electrodes shows an excellent amplitude signal in Alpha waves but they show the lowest amplitude of the signal in average compared with the standard sintered Ag/AgCl ring electrodes and the sputtered IrO_2 electrodes.

In [4], sputtered TiN thin films deposited with a pumping speed of 9 l/s and a power of 2.2 kW, and nitrogen gas flow of 3.4 sccm showed a resistance in the range of 27×10^{-6} Ohm*cm to 33×10^{-6} Ohm*cm. Comparing with the sputtered TiN films resistance fabricated in this work, we believe that their performance as EEG electrodes will be improved.

IV CONCLUSIONS

The knowledge of the neural activity in various parts of the brain has motivated the development of electrodes (non-invasive and invasive). The electrical performance of and the comparison between different type of electrodes for application in EEG measurements was presented. Sputtered TiN electrodes, standard sintered Ag/AgCl ring electrodes and sputtered IrO_2 electrodes were used in a braincap for monitoring the frontopolar position in patients according to the standard configuration 10-20 system. The experimental results show a better performance of the sputtered IrO_2 electrodes (high-amplitude signal average) compared with the standard sintered Ag/AgCl ring electrodes and sputtered TiN electrodes.

Sputtered IrO_2 electrodes have shown good performance as stimulating electrodes (high charge delivery capacity and low, constant impedance over the entire frequency range for neural stimulation) [5-6], and with these experiments they promise to be a good solution as recording electrodes in non-invasive EEG.

In all experiments electrolytic gels were used, but the results promises a new opportunity for fabricating a dry sputtered IrO_2 electrodes that can penetrate the outer skin layer (5-10 μm thick), called *Stratum Corneum* (for avoiding its high-impedance characteristics) without the use of the electrolytic gel. Moreover, sputtered IrO_2 electrodes do not present the known problems that Ag/AgCl electrodes showed in contact with biological tissue; the silver chloride on the surface dissolves and causes inflammations due to its toxicity [4].

Sputtered IrO_2 electrodes could have therapeutic value for patients with profound sensory or motor dysfunction. Such neuroprosthetic applications could be the restoration of limited, but functional vision to the blind or hearing to the deaf [6-8]. Also, electrode arrays with larger numbers of electrodes could provide greater therapeutic function than the use of only few electrodes.

The new direction in research by this emerging technology will soon require neural electrode arrays for stimulating and recording containing hundreds of electrodes.

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