Multichannel-Electroencephalography measurements with dry electrodes

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Introduction

BIOSIGNAL ELECTRODE

EEG measurement
• Potential fluctuations on subjects scalp
• 32-256 electrodes

Ag/AgCl electrodes
• "Gold standard"
• Need for gel or paste

Drawbacks
• Preparation complex and time-consuming
• Risk of skin irritation and hair damage
• Limited lifetime and stability of electrolyte
• Risk of conductive bridges
Introduction

DRY ELECTRODES

Concepts [1]
- Precious metals
- Graphite electrodes
- Microneedles
- Photrodes

TiN electrodes
- Conductive-type material
- Chemically stable, unaffected by sweat [2]
- Excellent mechanical properties
- Outstanding biocompatibility

Ti/TiN disc electrodes

**TIN\_x ELECTRODE**

<table>
<thead>
<tr>
<th></th>
<th>Sample A</th>
<th>Sample B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>16 mm</td>
<td>16 mm</td>
</tr>
<tr>
<td>Height</td>
<td>3 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>TiN_x layer thickness</td>
<td>1.45 µm</td>
<td>0.97 µm</td>
</tr>
<tr>
<td>X (%N / %Ti)</td>
<td>0.94</td>
<td>1.34</td>
</tr>
<tr>
<td></td>
<td>close-stoichiometric</td>
<td>over-stoichiometric</td>
</tr>
</tbody>
</table>

SEM micrographs of sample B

a) Top section

b) Cross section

Magnification: $10^5$  
1 μm
Ti/TiN disc electrodes

EEG TEST SETUP

Fp2

POz

Ag/AgCl

TiN
Ti/TiN disc electrodes

EEG TEST SETUP

![Diagram of EEG test setup with Ti/TiN disc electrodes and Ag/AgCl and TiN markers at Fp2 and POz locations.](image-url)
Ti/TiN disc electrodes

PARAMETERS

\[
RMSD = \sqrt{\frac{\sum_{i=1}^{n} (w_i - d_i)^2}{n}}
\]

\[
RMSDN = \sqrt{\frac{\sum_{i=1}^{n} \left( \frac{w_i}{|w|_{\text{max}}} - \frac{d_i}{|d|_{\text{max}}} \right)^2}{n}}
\]

\[
w\quad \text{- Reference Ag/AgCl}
\]

\[
d\quad \text{- TiN or second Ag/AgCl}
\]
<table>
<thead>
<tr>
<th>Used electrolyte</th>
<th>Recording</th>
<th>Sample A</th>
<th></th>
<th>Sample B</th>
<th></th>
<th>Dual Ag/AgCl</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RMSD (µV)</td>
<td>RMSDN (%)</td>
<td>RMSD (µV)</td>
<td>RMSDN (%)</td>
<td>RMSD (µV)</td>
<td>RMSDN (%)</td>
</tr>
<tr>
<td>EEG paste</td>
<td>Resting EEG</td>
<td>4.5</td>
<td>6.4</td>
<td>6.7</td>
<td>21.0</td>
<td>6.3</td>
<td>16.7</td>
</tr>
<tr>
<td>EEG paste</td>
<td>Eye blinking</td>
<td>5.8</td>
<td>1.3</td>
<td>15.0</td>
<td>6.6</td>
<td>6.2</td>
<td>4.7</td>
</tr>
<tr>
<td>EEG paste</td>
<td>Alpha activity</td>
<td>5.1</td>
<td>8.0</td>
<td>10.0</td>
<td>18.2</td>
<td>5.8</td>
<td>15.8</td>
</tr>
<tr>
<td>Skin oil</td>
<td>Resting EEG</td>
<td>7.6</td>
<td>9.5</td>
<td>9.3</td>
<td>20.6</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Skin oil</td>
<td>Eye blinking</td>
<td>9.4</td>
<td>2.7</td>
<td>20.4</td>
<td>5.7</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Skin oil</td>
<td>Alpha activity</td>
<td>8.5</td>
<td>10.1</td>
<td>9.3</td>
<td>17.1</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Hair shampoo</td>
<td>Resting EEG</td>
<td>5.1</td>
<td>8.4</td>
<td>8.8</td>
<td>11.3</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Hair shampoo</td>
<td>Eye blinking</td>
<td>7.5</td>
<td>2.1</td>
<td>16.8</td>
<td>8.8</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Hair shampoo</td>
<td>Alpha activity</td>
<td>5.0</td>
<td>9.0</td>
<td>9.4</td>
<td>10.3</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
CONCLUSION

• Novel electrode based on Ti substrate and homogeneous layer of TiN

• Signal quality mainly influenced by
  • spatial distance of electrodes
  • TiN composition

• Applicable for recording EEG with sufficient signal quality

• Insufficient hair layer penetration

Ti/TiN pin electrodes

AIMS

- New design for better hair layer penetration
- Investigation of application parameters
- Further optimization of TiN layer composition
- Need for automated electrode positioning and adduction
EEG cap

ELECTRODE ADDUCTION

TiN electrode
EEG cap

ELECTRODE LAYOUT

Elastic Net

- Adaptable to head geometry
- Up to 300 channels
- Equidistant
- Modular
- Breathable
EEG cap

ELECTRODE LAYOUT

- quasi-equidistant silicone network
- 32 TiN & Ag/AgCl electrodes at 10-20 positions
- Actual distance: 24 mm ÷ 2.2 mm
EEG cap

COMPLIANT ACTUATORS

- Compliant, monolithic structures based on biocompatible materials
- One degree of freedom: rotation, translation or screw motion
- High potential for automated, reliable and reproducible electrode adduction
EEG cap

ELECTRODE ADDUCTION

Compliant mechanism for electrode placement
## Ti/TiN pin electrodes

### ELECTRODE DEVELOPMENT

<table>
<thead>
<tr>
<th>Generation</th>
<th>Top view</th>
<th>Side view</th>
<th>Diameter</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
<td>16 mm</td>
<td>3 mm</td>
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<tr>
<td>2</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
<td>6 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>3</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
<td>4 mm</td>
<td>5 mm</td>
</tr>
<tr>
<td>4</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
<td>3.5 mm</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>
Impedance

- Hewlett Packard 4192A LF analyzer
- Frequency range [Hz]:

<table>
<thead>
<tr>
<th>Range</th>
<th>Start</th>
<th>Stop</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range 1</td>
<td>5</td>
<td>500</td>
<td>1</td>
</tr>
<tr>
<td>Range 2</td>
<td>500</td>
<td>10k</td>
<td>10</td>
</tr>
</tbody>
</table>
- Time per sample: 2s
- Four-electrode setup
- Test in NaCl solution
Ti/TiN pin electrodes

IMPEDANCE

![Graph showing impedance vs. frequency for Ti/TiN and Ag/AgCl electrode types.](image)

- **Graph a)**: Absolute value (Ω) vs. Frequency (kHz)
- **Graph b)**: Phase (°) vs. Frequency (kHz)
Ti/TiN pin electrodes

OPEN CIRCUIT POTENTIAL

STD Ag/AgCl electrodes:  7 mV
STD Ti/TiN electrodes:  63 mV
EEG TESTS

EEG acquisition
• Parallel recording using distinct conditions
  ŷ Spontaneous EEG
  ŷ Alpha activity
  ŷ Eye blinking and movement artefacts
  ŷ Pattern reversal VEP (Checkerboard)

Amplification & Processing
• Two 64 channel amplifiers (TNSi)
• Unipolar channel montage
• Patient ground at AFz
• Subsequently filtered using a 2-30 Hz bandpass

Haueisen – IMEKO Jena – 31st August 2011
Ti/TiN pin electrodes

RECORDING SETUP
18 of the 32 Ti/TiN electrodes delivered stable biosignals.

Other 14 Ti/TiN electrodes were automatically deactivated by the biosignal amplifier caused either by electrode–skin impedance values above 256 kΩ (DC) or values exceeding 150 mV relative to CAR.

Only these 18 permanently activated Ti/TiN electrodes and their corresponding adjacent Ag/AgCl electrodes are considered for further evaluation.
<table>
<thead>
<tr>
<th>EEG test</th>
<th>RMSD (µV)</th>
<th>STD of RMSD (µV)</th>
<th>RMSDN (%)</th>
<th>STD of RMSDN (%)</th>
<th>RMSD (µV)</th>
<th>STD of RMSD (µV)</th>
<th>RMSDN (%)</th>
<th>STD of RMSDN (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting state</td>
<td>4.6</td>
<td>1.9</td>
<td>27.2</td>
<td>4.5</td>
<td>4.0</td>
<td>1.4</td>
<td>22.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Alpha activity</td>
<td>3.4</td>
<td>1.3</td>
<td>16.4</td>
<td>4.0</td>
<td>3.5</td>
<td>1.5</td>
<td>16.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Eye blinking</td>
<td>4.1</td>
<td>0.8</td>
<td>13.3</td>
<td>6.0</td>
<td>4.9</td>
<td>2.5</td>
<td>12.2</td>
<td>6.4</td>
</tr>
<tr>
<td>Pattern reversal VEP</td>
<td>0.5</td>
<td>0.2</td>
<td>14.0</td>
<td>7.6</td>
<td>0.5</td>
<td>0.2</td>
<td>14.6</td>
<td>9.5</td>
</tr>
</tbody>
</table>

* Values represent mean over all channels and 30 sec of data
Ti/TiN pin electrodes

EEG OVERLAY
Ti/TiN pin electrodes

SPECTRUM OVERLAY
Ti/TiN pin electrodes

PATTERN REVERSAL VEP
Ti/TiN pin electrodes

VEP MAPPING

\[ t = 000 \text{ ms} \]
Ti/TiN pin electrodes

VEP MAPPING

Ag/AgCl

TiN
Ti/TiN pin electrodes

VEP MAPPING

Ag/AgCl

TiN
CONCLUSION

- Special electrode shape for hair layer penetration
- Ti substrate + homogeneous layer of TiN
- Applicable for recording EEG with sufficient signal quality

- Fluidic-driven Actuator for adduction of electrode

MULTIPIN ELECTRODES

- Impedance decreases with number of interconnected electrode „pins“
- Signal quality remains stable
- Novel flexible PU/TiN „Multipin“ EEG electrodes
PU/TiN multipin electrodes

ELECTRODE SHAPE

Weight 256 Ti based electrodes:
Weight 256 PU based electrodes:
PU/TiN multipin electrodes

EEG TEST SETUP

Fp2

POz

Ag/AgCl
TiN
PU/TiN multipin electrodes

EEG TEST SETUP

Fp2

Reference signal

Test signal

POz

Ag/AgCl

TiN
## SIGNAL QUALITY

<table>
<thead>
<tr>
<th>EEG test</th>
<th>RMSD (µV)</th>
<th>RMSDN (%)</th>
<th>Variance of EEG (Ag/AgCl)</th>
<th>Variance of EEG (PU/TiN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting state</td>
<td>8.4</td>
<td>13.6</td>
<td>63.0</td>
<td>53.6</td>
</tr>
<tr>
<td>Eye blinking</td>
<td>10.8</td>
<td>15.6</td>
<td>186.5</td>
<td>185.2</td>
</tr>
<tr>
<td>Pattern reversal VEP</td>
<td>1.0</td>
<td>27.4</td>
<td>2.4</td>
<td>2.9</td>
</tr>
</tbody>
</table>

* Values represent mean over 30 sec of data
PU/TiN multipin electrodes

CONCLUSION

• Applicable for recording EEG with sufficient signal quality
• Better hair layer penetration and lower impedance
• Light-weight

• Current work: electrode wear-off problem and next generation EEG cap
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