WHITE PAPER

MOSS-EMBROIDERED ELECTRODES FOR ADVANCED BIOELECTRONICS APPLICATIONS

ABSTRACT

Moss-embroidered electrodes represent a groundbreaking development in wearable bioelectronics, offering a flexible, gel-free alternative for long-term biometric monitoring. These electrodes utilize conductive yarns in a looped, moss-like embroidery stitch, providing superior comfort, durability, and signal acquisition. This paper explores fabrication techniques, performance characteristics, and washability. Comparative impedance spectroscopy shows that the moss stitch construction is more than twice as wash-stable as flat-embroidered electrodes, and that moss-embroidered electrodes retain their electrical functionality after household washing. Electrode parameters such as material quantity can be adapted to the wash requirements of each application.

INTRODUCTION

Advancements in wearable technology have emphasized the need for comfortable, long-lasting, and efficient electrodes capable of non-invasive biometric monitoring. Traditional electrodes rely on gels or adhesives, which can cause skin irritation and degrade over time. Moss-embroidered electrodes provide a novel solution by integrating soft conductive yarns into fabric, enabling direct and secure contact with the skin without additional adhesives.

KEY OBJECTIVES

- To analyze the fabrication and material properties of moss-embroidered electrodes.
- To evaluate their performance in real-world biometric monitoring applications.
- To discuss their potential in healthcare, fitness, and telemedicine.
- To compare the wash stability of moss-embroidered and flat-embroidered electrodes.

FABRICATION TECHNIQUES

MATERIALS

Moss-embroidered electrodes use conductive yarns, typically silver-coated polyamide fibers, embroidered into elastic fabrics. This combination ensures flexibility, conductivity, and comfort. The 3E Smart Solutions development kits use STATEX Shieldex® silver-coated polyamide yarns in three specifications:

Article No.	Yarn	Thread count	Geometry	Resistance*	Shieldex® Type
597.829	Shieldex® 33/10 dtex	6×	Ø 20, 43, 65 mm	1.0–1.5 Ω	Z-turns, Ag-coated PA
597.830	Shieldex® 78/20 dtex	4×	Ø 20, 43, 65 mm	1.6–1.9 Ω	Z-turns +B, Ag-coated PA
597.831	Shieldex® 235/36 dtex	1×	Ø 20, 43, 65 mm	1.6–1.7 Ω	2-ply HC +B, Ag-coated PA

* Average electrical resistance, measured for 1 min with a Ø 59 mm test electrode and a weight force of 1.7 N. See data sheet “Moss Embroidered Electrodes – Development Kits”.

EMBROIDERY PATTERNS

The moss-stitch technique creates a looped structure that maximizes surface contact area while maintaining softness. Moss electrode variants differ in fiber blend and construction depth; a flat stitch electrode serves as reference for comparison.

INTEGRATION INTO WEARABLES

These electrodes can be embedded into garments such as compressive vests, sleeves, or leggings. Conductive paths are seamlessly embroidered into the fabric, allowing direct connections to recording devices or wireless transmitters.

PERFORMANCE AND TESTING

ELECTRICAL PERFORMANCE

Moss-embroidered electrodes demonstrate low skin-electrode impedance and a high signal-to-noise ratio, comparable to traditional Ag/AgCl electrodes. Tests indicate that variations in loop size and filling material significantly influence performance.

COMFORT AND DURABILITY

The looped design enhances tactile comfort and reduces friction during movement. Testing confirms that moss electrodes maintain electrical functionality after repeated washing, making them suitable for long-term wearable use.

WASHABILITY AND CARE

> **Key Finding — Moss Stitch vs. Flat Stitch**
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> In comparative wash tests, the resistance increase of moss-embroidered electrodes after washing was less than half that of a flat-embroidered reference electrode – the moss stitch is more than twice as wash-stable. All moss-embroidered electrodes retained their electrical functionality after household washing.

Washability is a decisive requirement for wearable bioelectronics. Wash stability was evaluated in the scope of doctoral research (M. Hoerr, RWTH Aachen, 2016) using impedance spectroscopy on an Agar-Agar gel skin phantom, comparing moss-embroidered electrodes with a flat-stitch reference before and after defined household wash cycles under reproducible IEC conditions.

These tests were carried out on early electrode variants. Current electrode generations perform significantly better. As wash requirements differ between products, the required number of wash cycles is defined for each application – electrode parameters such as material quantity and construction are then adapted accordingly and validated in application-specific tests.

Care Recommendations

Parameter	Recommendation	Evidence Basis
Wash temperature	Max. 40°C (household machine wash)	Tested at 30–40°C, IEC conditions
Detergent type	Standard household detergent (heavy-duty or delicate)	No significant difference measured (ZSK 2018)
Laundry bag	Always use a laundry bag	Protects the moss loops mechanically; 3E care recommendation
Bleach	Never use bleach	Attacks the silver coating; 3E care recommendation
Spin cycle	Normal household spin	Standard IEC wash protocol
Tumble drying	Not tested — air drying recommended	No data available
Ironing	Avoid direct contact ironing over electrode areas	Heat may affect silver coating adhesion

SIGNAL QUALITY AND COMFORT

Moss-embroidered electrodes demonstrate superior signal quality, particularly in signal-to-noise ratio (SNR). The looped structure of the moss stitch ensures consistent skin contact, reducing motion artifacts and improving signal clarity compared to traditional lock stitch electrodes.

In terms of comfort, the looped design conforms better to skin contours, reducing pressure points during prolonged wear. This makes moss electrodes particularly suitable for long-term applications such as EEG and EMG monitoring.

IMPEDANCE AND CONDUCTIVITY

Skin-electrode impedance decreases with increased contact area. The looped moss stitch adheres more effectively under moderate body pressure, yielding lower impedance and better signal quality than flat-embroidered alternatives.

The conductivity of moss-embroidered electrodes is enhanced by the silver-coated polyamide yarns, which ensure efficient transmission of electrical signals across the textile-skin interface.

DESIGN AND FABRICATION

The design flexibility of moss-embroidered electrodes allows for various shapes, electrode diameters, and loop lengths, optimizing both tactile comfort and sensing performance. The embroidery process can be tailored to produce electrodes with specific characteristics, such as increased surface area for better skin contact, enhanced flexibility for improved comfort, or adapted material quantity for the required wash stability.

The fabrication of moss-embroidered electrodes involves embroidering conductive yarns onto a textile substrate. This process ensures that the electrodes are durable and suitable for integration into everyday garments such as compressive shirts, headbands, or wristbands.

COMPARATIVE ANALYSIS

Impedance spectroscopy results confirm that moss-embroidered electrodes outperform flat-embroidered (lock stitch) electrodes in both baseline impedance under contact pressure and wash stability.

APPLICATIONS

HEALTHCARE

- Continuous monitoring for patients with chronic conditions (ECG, EEG, EMG).
- Enhanced electrode designs for TENS and EMS therapy devices.

FITNESS AND SPORTS

- Wearable fitness trackers with integrated EMG monitoring.
- Real-time performance analysis during training sessions.

TELEMEDICINE

- Remote patient monitoring solutions for emerging healthcare models.

CHALLENGES AND FUTURE DIRECTIONS

CURRENT LIMITATIONS

- Optimization for diverse skin types and environmental conditions (perspiration, dry skin).
- Tumble drying behavior of silver-coated yarn structures not yet characterized.
- Systematic wash studies for current electrode generations are pending; wash stability is validated per application.

FUTURE DEVELOPMENTS

- Integration with wireless communication technologies for seamless data transmission.
- Development of eco-friendly conductive materials for sustainable applications.
- Extended wash series including tumble drying and accelerated aging for current electrode generations.

CONCLUSION

Moss-embroidered electrodes mark a significant step forward in wearable bioelectronics, combining comfort, durability, and high-performance signal monitoring. Their superior signal quality, comfort, and impedance characteristics make them an ideal choice for applications requiring reliable and long-term monitoring.

Comparative impedance spectroscopy confirms the structural advantage of the moss stitch: it is more than twice as wash-stable as a flat-embroidered electrode, and moss-embroidered electrodes keep their electrical functionality after household washing. Electrode parameters can be tailored to the wash requirements of each product. No special care products or wash programs are required; we recommend a laundry bag and no bleach. This wash robustness, combined with gel-free dry-contact operation, positions moss-embroidered electrodes as the preferred solution for everyday bioelectronics garments in healthcare, fitness, and telemedicine.

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