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Determination of dielectric properties of mimicking biological tissues by electrochemical impedance spectroscopy

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Introduction and objective

Tissue-mimicking materials are widely used as substitutes in many medical branches, including surgical procedures, medical imaging, machine calibration, training, and simulations. Usually, these materials are fabricated either by chemical synthesis or additive manufacturing (3D printing), to mimic the mechanical, optical or, as in the present work, electrical properties of the targeted tissues.

The aim of this work is to fabricate a biomaterial that mimics, as closely as possible, the dielectric properties of bone in the context of spinal surgery, where low-frequency electrical stimulation is performed to verify the correct placement of titanium pedicle screws around the nerve structure [1].

Synthesis of the tissue-mimicking materials

In order to obtain a tissue mimicking the bone of the spine, different mixtures of hydrogels containing chitosan and hydroxyapatite (HAp) were prepared by varying the concentrations and/or the pH of the hydrogels.

➤ Preparation of 20 mL of chitosan-based gel:

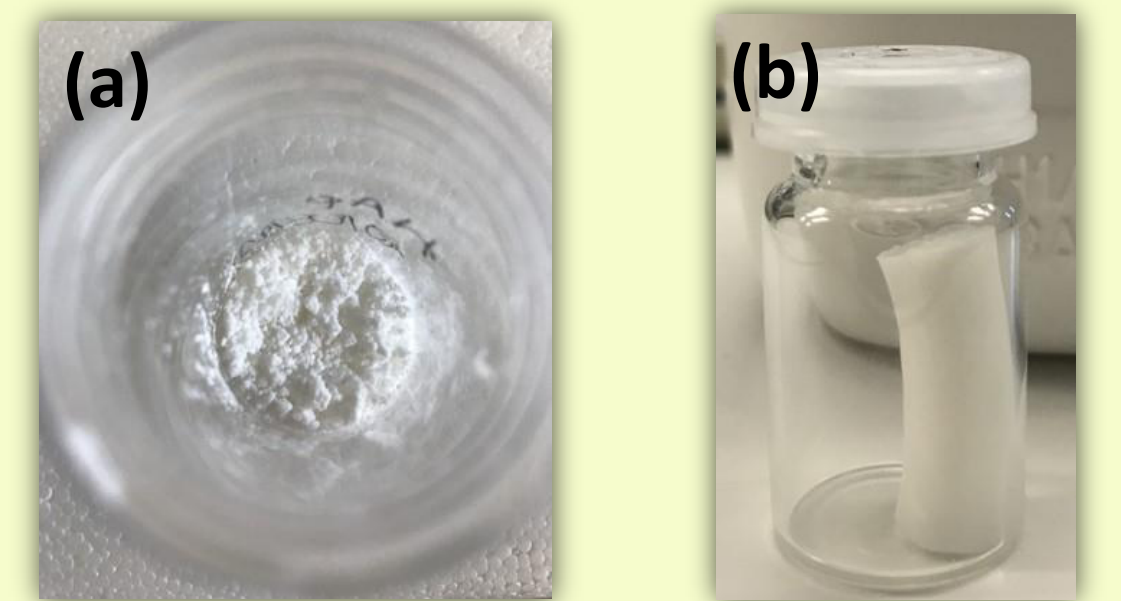
- 120 μ L of acetic acid + 240 μ L NaOH + distilled water
- Addition of x mg of chitosan (x : 40 mg (1), 50 mg (2) and 60 mg (3)) to obtain different viscosities



Chitosan-based gel from least viscous (1) to most viscous (3)

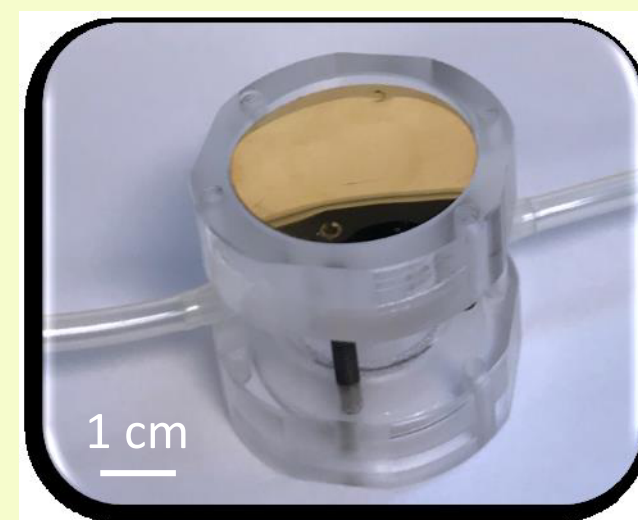
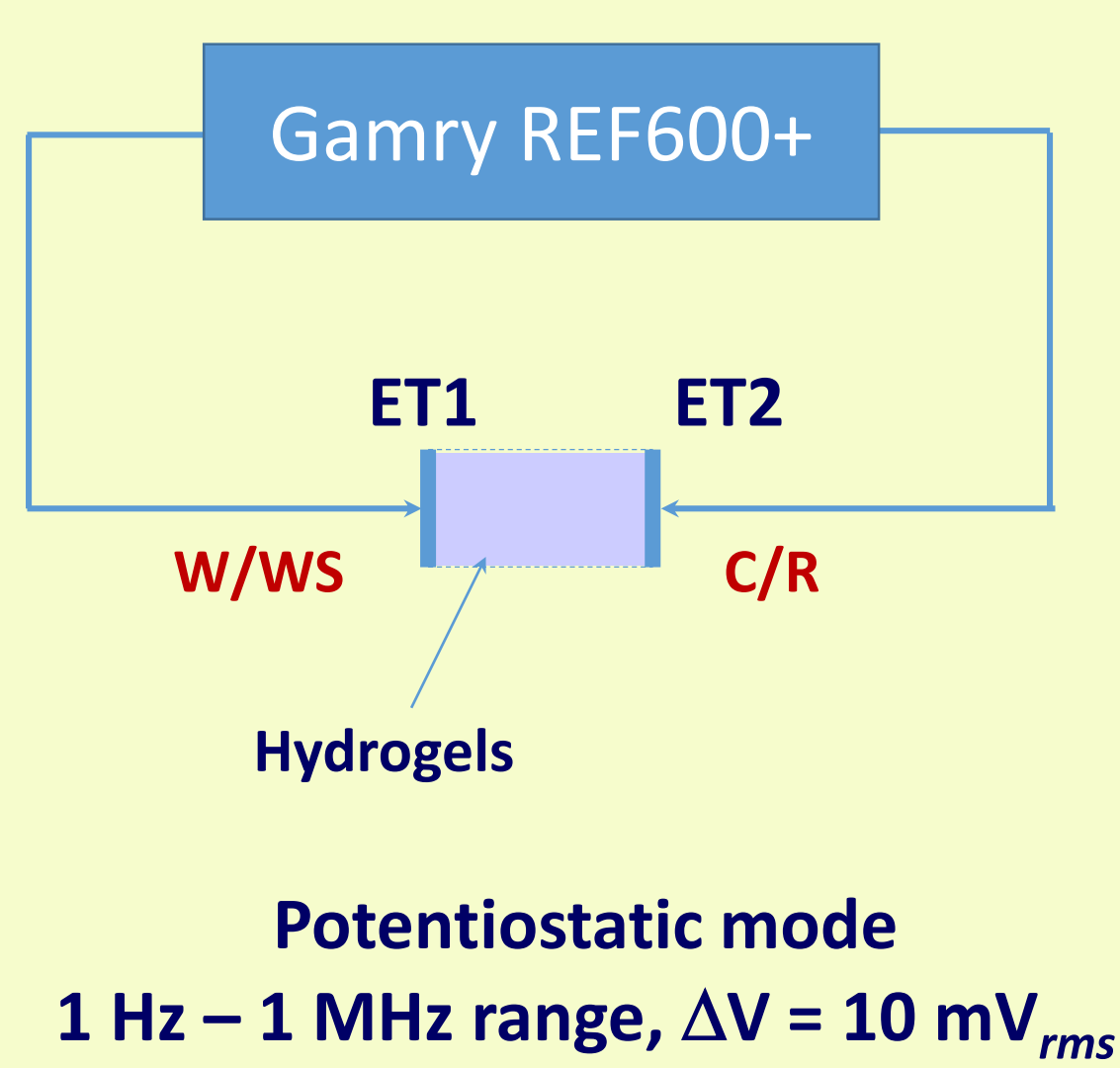
➤ Preparation of HAp-based hydrogels: a two-step procedure (synthesis of HAp nanoparticles and mixing with gelatin to obtain HAp-based gels in desired concentration)

- (a) HAp nanoparticles: mixing of $\text{Ca}(\text{OH})_2 + \text{NH}_4\text{H}_2\text{PO}_4$ in pure water, curing under magnetic stirring for 48h; recovery by Büchner filtration; oven drying
- (b) Carrot of HAp-based gel after mixing HAp nanoparticles and gelatin

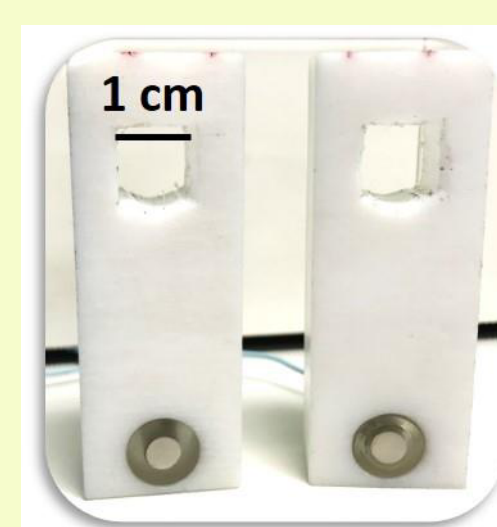


Experimental set-up

Two-electrode set-up

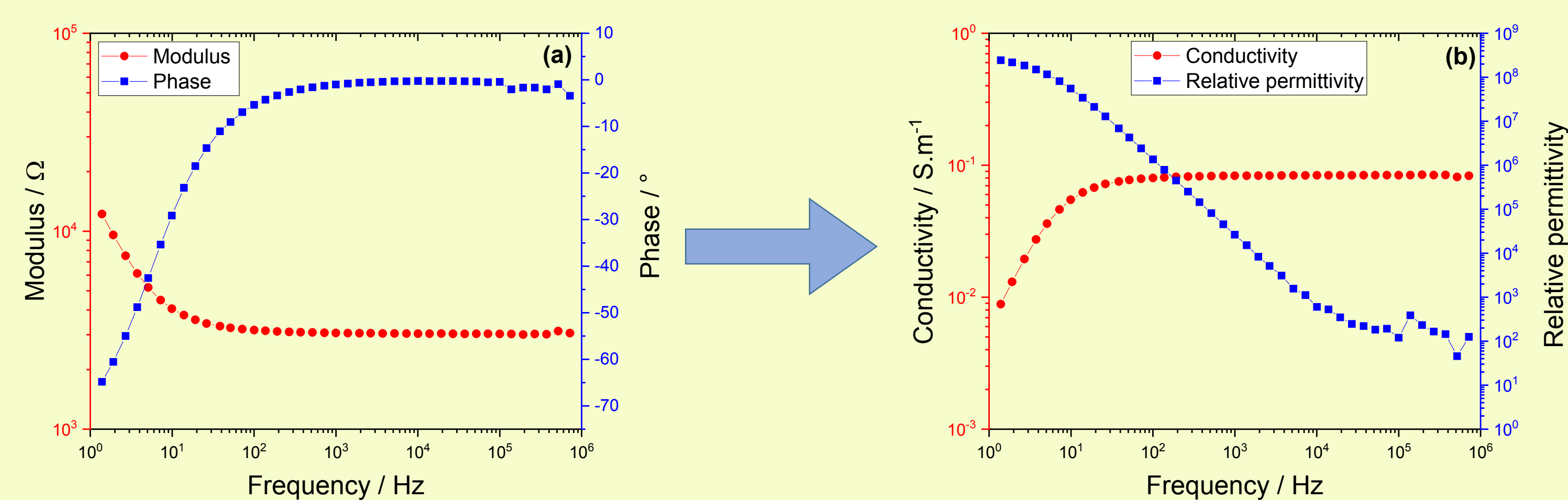


Cell #1: Gold planar electrodes



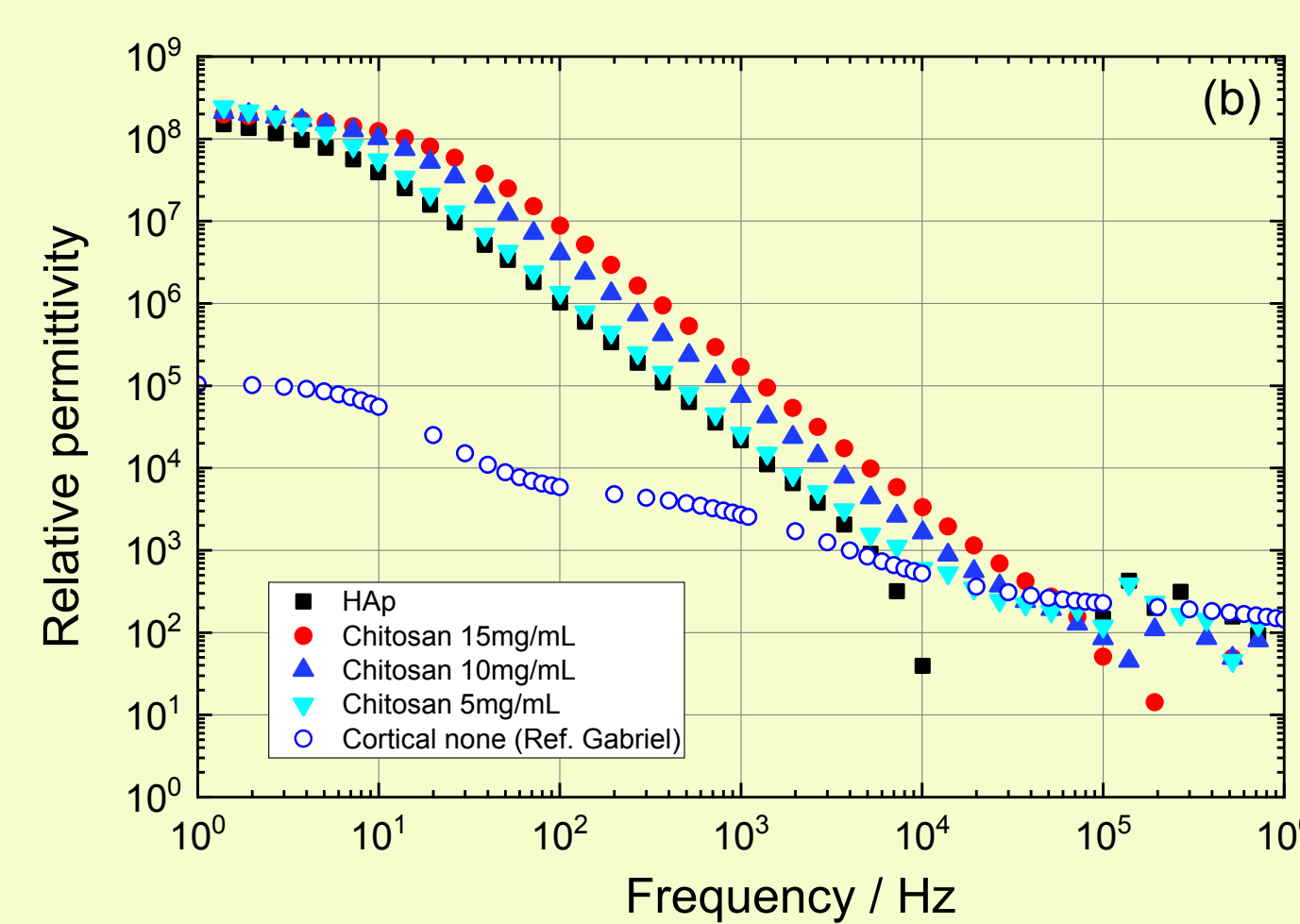
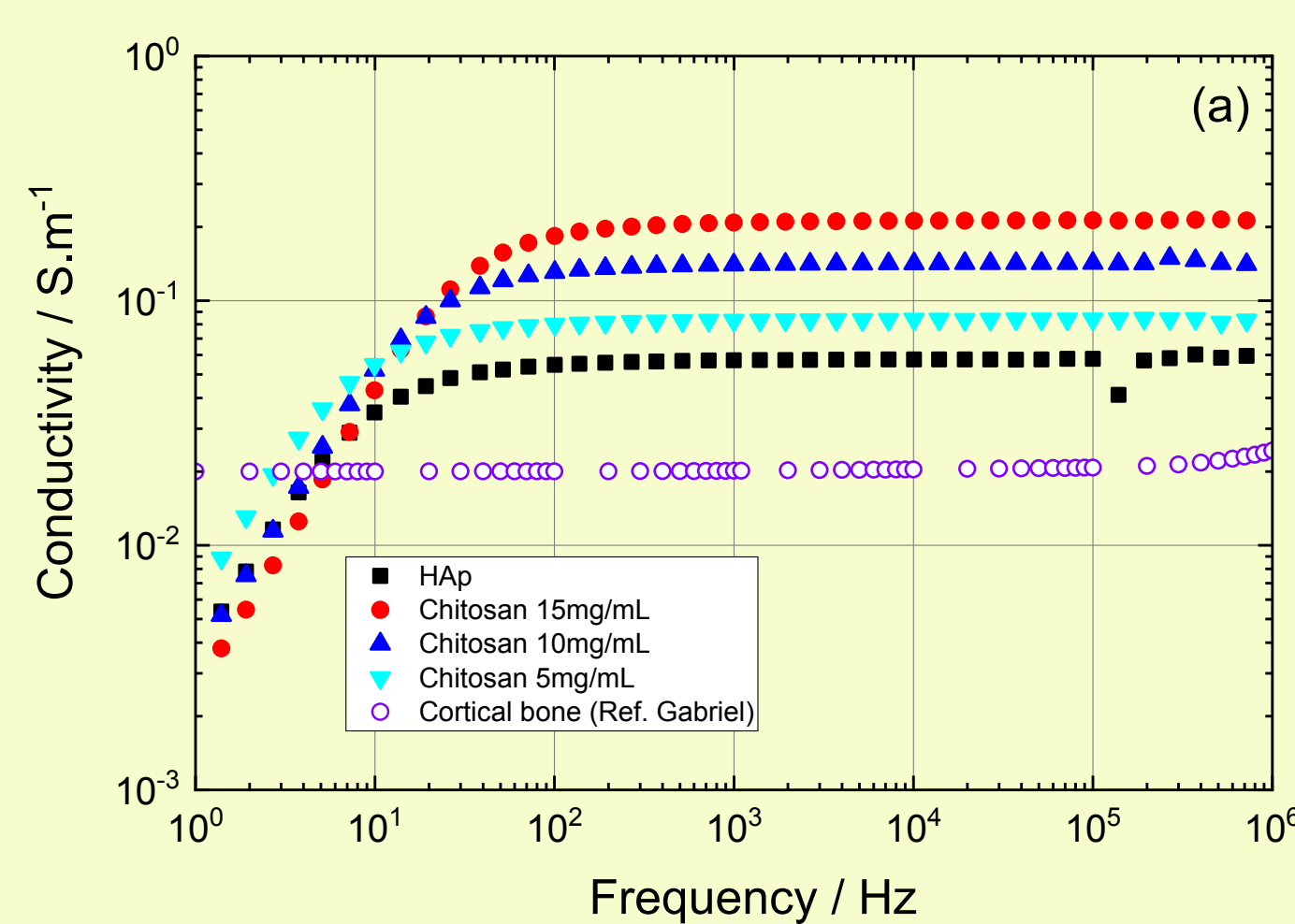
Cell #2: Platinum rod electrodes

$$Z_{measured} = \frac{1}{j\omega C} \text{ with } C = \frac{\epsilon_0 \times \epsilon_r \times S}{d} \rightarrow \epsilon_r = \frac{d}{j\omega\epsilon_0 S Z_{measured}} \quad \sigma = j\omega\epsilon_0\epsilon_r$$

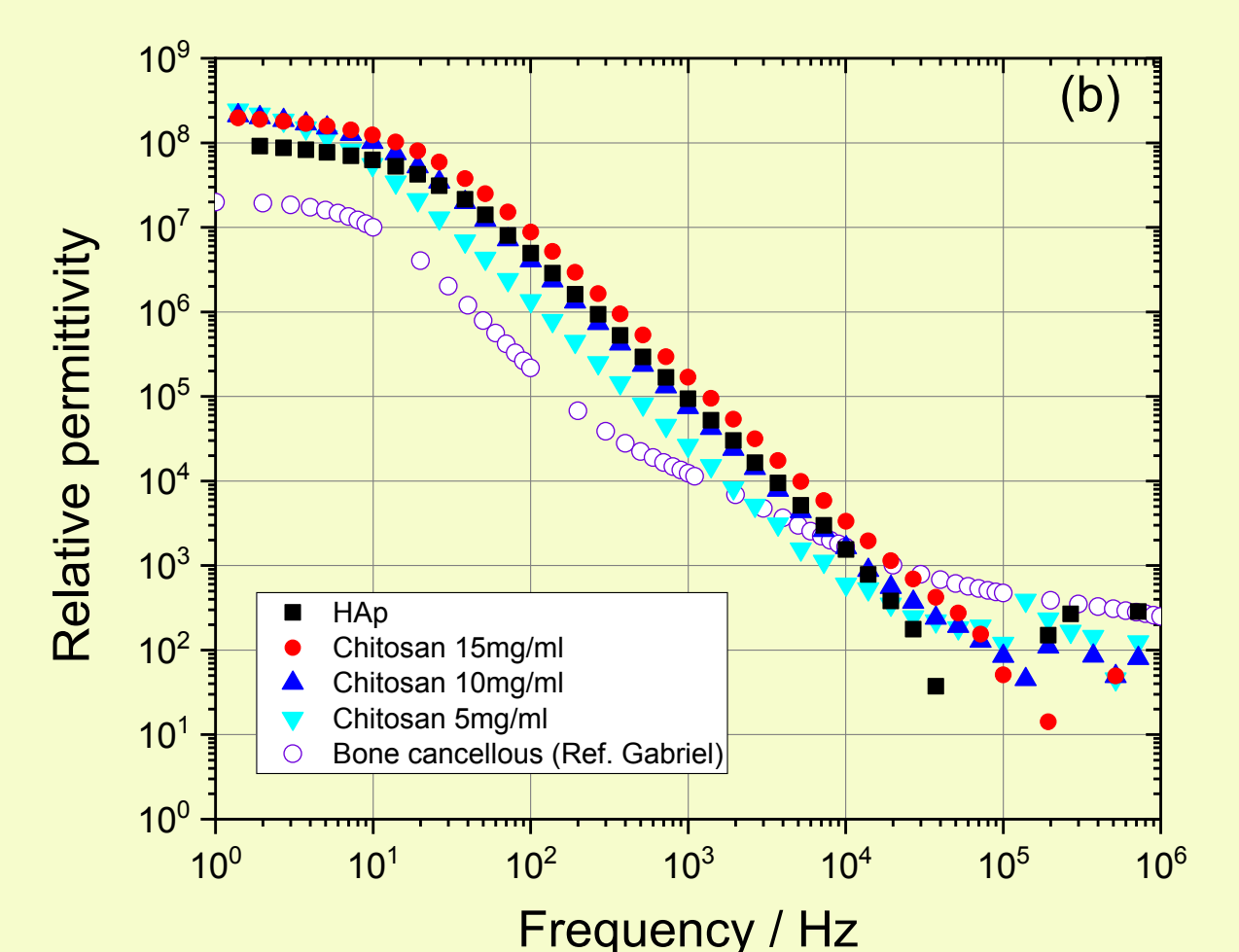
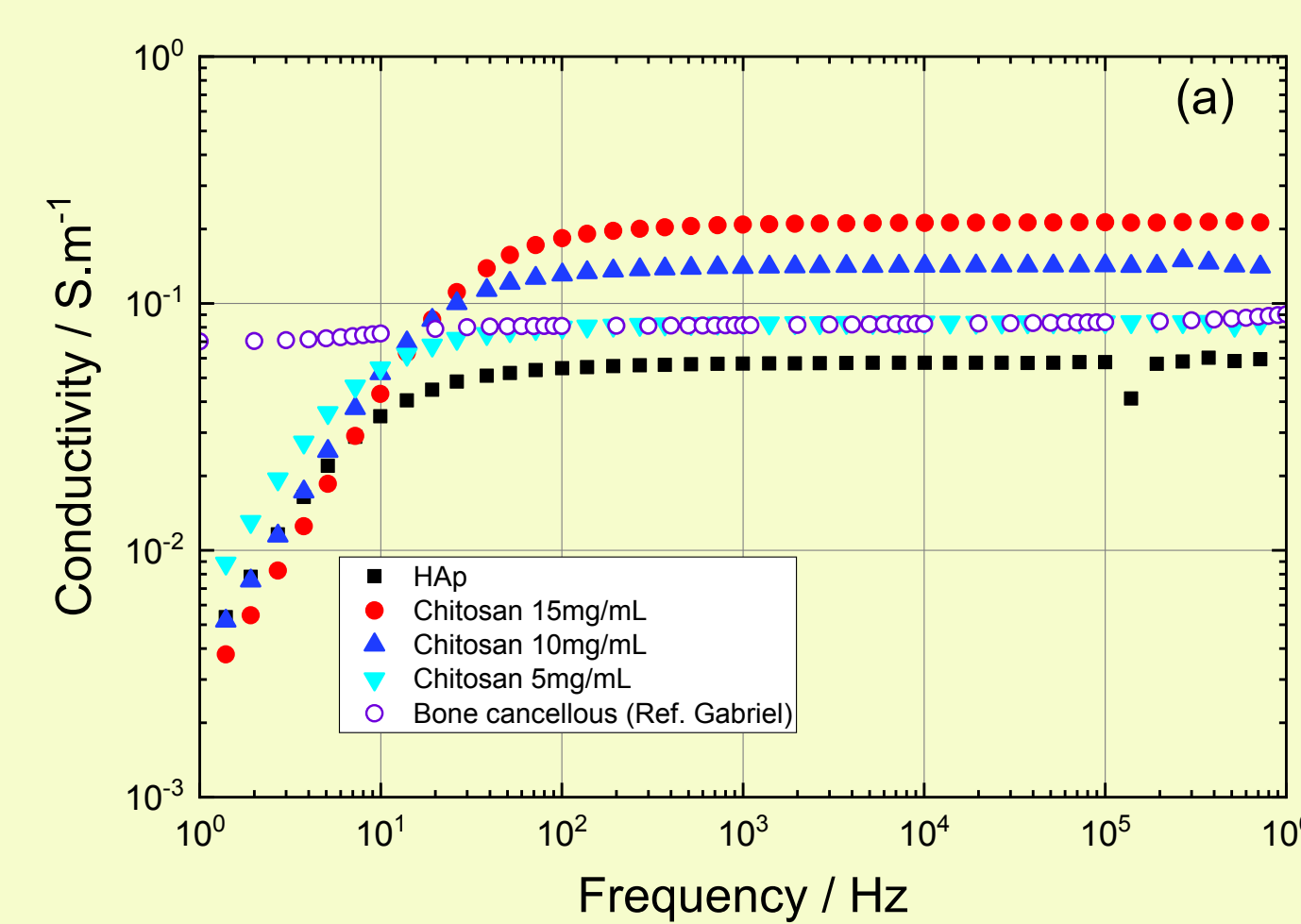


(a) Example of impedance spectra (Bode diagram) and (b) conductivity and relative permittivity of hydrogel containing chitosan (5mg/ml)

Conductivity and relative permittivity of synthesized hydrogels



Electrical properties of different mimicking biological tissues compared to those of cortical bone measured by Gabriel et al. [2] (a) conductivity and (b) relative permittivity



Electrical properties of different mimicking biological tissues compared to those of cancellous bone measured by Gabriel et al. [2] (a) conductivity and (b) relative permittivity

Conclusions

Different mixtures of hydrogels containing chitosan and HAp have been chemically prepared by varying the concentrations and/or the pH of hydrogel to obtain a tissue mimicking the bone of the spine. Electrochemical impedance spectroscopy measurements have been performed within these hydrogels to determine their electrical properties from 1 Hz to 1 MHz. It has been showed that hydrogels with 5mg/ml chitosan have similar electrical properties than those of cancellous bone.

References: [1] J. Zyss et al. Neurophysiologie Clinique. 2016, 46(3):234; [2] C. Gabriel et al. The dielectric properties of biological tissues: I. Literature survey, Phys. Med. Biol. 1996, 41(11):2231.