Biodegradable Wireless Microheaters for Transient Biomedical Implants

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Transient electronics show a great potential in the field of bioresorbable medical implants, for applications such as localized drug delivery for wound healing or following a surgical procedure.[1,2] Once their function is fulfilled, such implants naturally degrade and resorb in the body, which eliminates adverse long-term effects or the need for a secondary surgery to extract the implanted device.[3,4] Since biodegradable materials are water-soluble, the fabrication of such transient electronic circuits and devices requires special care and needs to rely solely on dry processing steps without exposure to aqueous solutions. A further challenge is the in-vivo powering of medical implants that are only constituted of biodegradable materials. This work describes the design, fabrication and testing of radio-frequency biodegradable magnesium (Mg) microresonators. To this end, an innovative microfabrication process with minimal exposure to aqueous media is developed to fabricate magnesium-based, water-soluble electronic components, without the need to fabricate and use fragile stencils. It consists of a novel sequence of only three steps: one physical vapor deposition, one photolithography, and one ion beam etching step. The frequency-selective wireless heating of different resonators is demonstrated.

Figure 1a illustrates the use of frequency-selective, biodegradable microresonators as power receivers and microheaters for transient electronics. Each resonator has a different resonance frequency (f_0) tuned by its geometrical parameters, which makes them selectively addressable. Using an external RF magnetic field, energy is coupled only into the frequency matched resonator where an electrical current is induced by electromagnetic induction, resulting in the Joule heating of that particular device only. The geometry of the microheaters, shown in Figure 1b, is commonly referred to as spiral resonator (SR). By adding a meander to the design, the current density locally increases by one to two orders of magnitude as computed by finite element method (FEM), which creates a local hot spot at a specific location. Figure 1c shows the details of the process flow used to produce the Mg resonators, based on ion beam etching. Our new process enables producing Mg microstructures without exposing the Mg layer to water based solutions over the entire fabrication process. Transfer to a biodegradable substrate will be implemented adopting a similar strategy as in ref.[5] Figure 1d shows a typical fabricated Mg SR with the geometrical parameters designed to tune its resonance frequency. The measured resonance frequencies of different SR geometries in air (full lines) and in water (dashed lines) are shown in Figure 1e. In air, a small gap variation of 10 µm induces a relatively large frequency shift of 0.28 GHz. In water, for the same gap variation, the frequency shift is only 0.01 GHz. Our measurements show that obtaining large frequency shifts in water requires larger geometrical variations (ΔR=280 µm, $\Delta f0$=0.57 GHz), which is also confirmed by FEM simulations. Figure 1f illustrates the wireless heating and breaking of a meander hot spot. The top images show a SR without Parylene passivation that was used in air. The images clearly show that the Mg meander hot spot is burnt by joule heating in the center. The bottom images show a SR with a 5 µm thick Parylene passivation layer used in water. In this configuration, the heat generated is strong enough to induce damage to the Parylene by creating a hole in it. In conclusion, the ability to selectively power and heat up microresonators made of biodegradable materials is a significant step towards the use of such devices as heating and triggering elements in implantable biodegradable devices, in particular for controlled drug release and thermal therapy.[1,2,6]

References

1. A. Tamayol *et al.*, *Sci. Rep*. **7**, 9220 (2017).
2. H. Tao *et al.*, *PNAS*. **111**, 17385–17389 (2014).
3. S.-W. Hwang *et al.*, *Science*. **337**, 1640–1644 (2012).
4. S.-K. Kang *et al., Nature.* **530**, 71–76 (2016).
5. S.-W. Hwang *et al.*, *Adv. Mater.* **26**, 3905–3911 (2014).
6. K. N. Noh *et al.*, *Small*. **14**, 1870015 (2018).

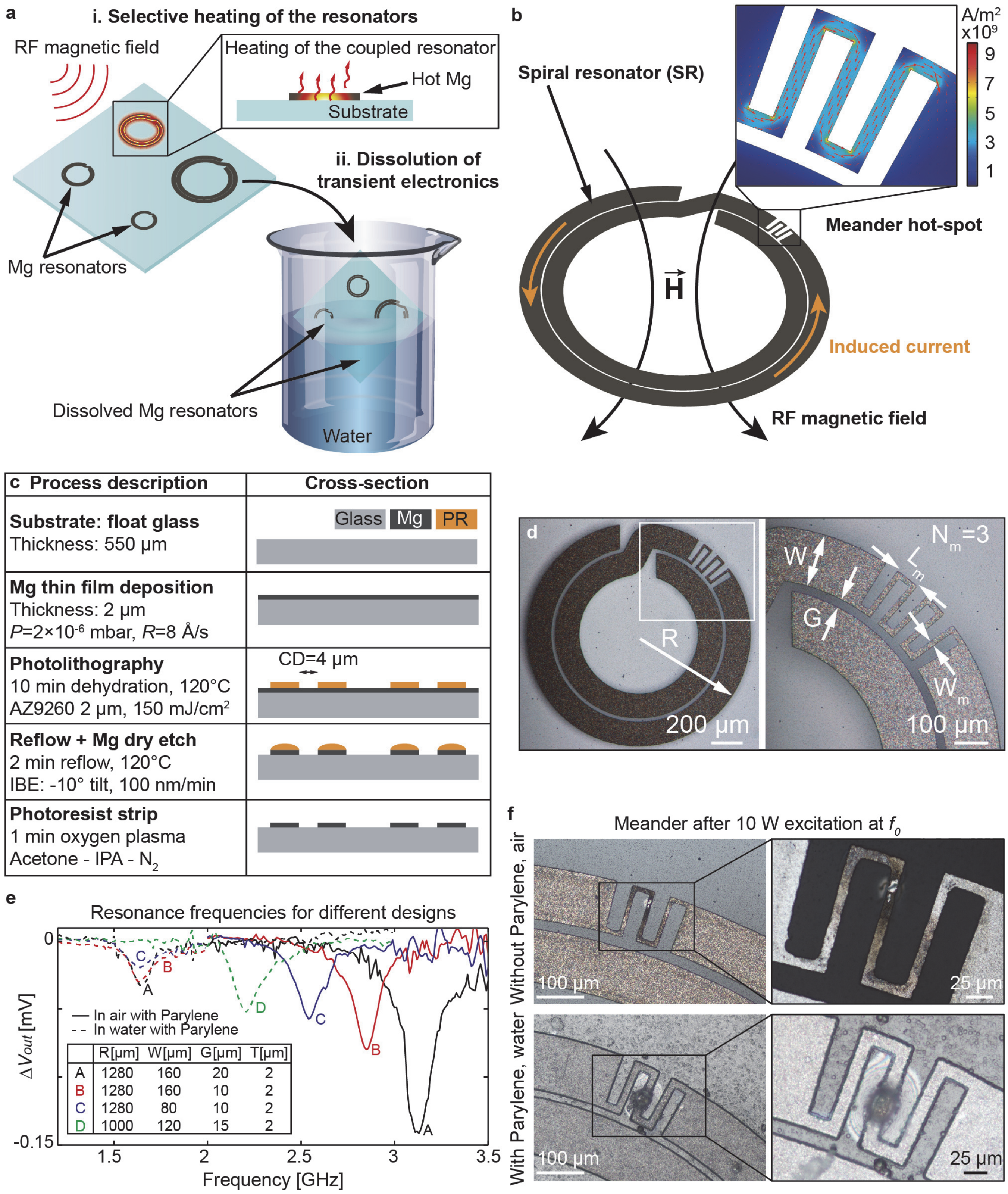

Figure 1: a) Concept of using frequency-selective, biodegradable microresonators as power receivers and microheaters for transient electronics. b) Design and FEM simulation of a spiral resonator (SR) with a meander hot spot to increase the induced current density. c) Fabrication process to produce biodegradable Mg electronics with minimal exposure to aqueous media. d) Optical microscope (OM) images of a fabricated Mg microresonator with the specific geometrical parameters enabling the tuning of the resonance at the desired frequencies. e) Resonance of different resonator geometries in air (full lines) and in water (dashed lines). In both cases, the devices are passivated with a Parylene layer (5 µm thick). f) OM images of the broken meander hot spots of the SRs after wireless heating. Top row shows Mg without Parylene passivation and bottom row shows Mg with a 5 µm Parylene passivation layer.