BIORESORBABLE FREQUENCY-SELECTIVE MAGNESIUM MICRO-RESONATORS FABRICATED BY ION BEAM ETCHING

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ABSTRACT

We present an innovative process to fabricate magnesium-based bioresorbable microelectromechanical systems (MEMS) by ion beam etching. This process enables the fabrication of thin biodegradable water-soluble passive electronic components with minimal exposure to aqueous media, in a simple physical vapor deposition, photolithography and dry etching sequence. We demonstrate the design, fabrication and characterization of frequency-selective magnesium RF micro-resonators in air and in water and compare the results to values obtained from both analytical model and FEM. Such resonators can be used as selectively-addressable RF power receivers for bioresorbable wireless implantable medical devices.

KEYWORDS: Bioresorbable Wireless Implantable Medical Devices, Ion Beam Etching, Microwave Resonators

INTRODUCTION

Transient electronic devices show high potential not only for electronic waste reduction, but also in the field of bioresorbable medical implants, for applications such as intensive care monitoring and localized drug delivery following a surgical procedure. Once their aim is achieved, the implants naturally degrade and are eliminated by the body, thus avoiding adverse long-term effects or the need for a second surgery for removal [1,2]. Among biodegradable water-soluble metals, magnesium (Mg) shows excellent biocompatibility and is already used in transient electronic devices. Various Mg fabrication methods have been reported in literature, including wet etching of thick Mg foils [2,3] and evaporation of thin Mg structures through stencils [1]. The method reported here consists in optimizing ion beam etching (IBE) to fabricate magnesium micro-resonators with a robust fabrication process that furthermore reduces exposure to aqueous media, without the need to fabricate and use fragile stencils.

MICRORESONATORS FABRICATION AND CHARACTERIZATION

Figure 1 shows details of the process flow, which consists of one physical vapor deposition, one photolithography, and one dry etching step. First a 2 µm thick Mg film is deposited by thermal evaporation (P=2.2 mbar, R=8 Å/s) on a 550 µm thick float glass substrate. Second, a photolithography step is performed. After a 10 min dehydration step on a hotplate at 120°C, a 2 µm thick layer of AZ9260 is spin coated on top of the Mg film. Patterns are exposed by direct laser writing at a dose of 150 mJ/cm^2. Resist is developed (AZ400K:H_2O/1:3.5) and a 2 min reflow on a hotplate at 120°C is performed to smoothen the resist profile and avoid re-deposition on the resist sidewalls during the subsequent IBE step. The IBE is performed with a sample tilt of -10° and an etch rate of 100 nm/min. The photoresist is removed in acetone after a 1 min O_2 plasma step. The wafer is finally rinsed in IPA and dried with N_2. For the characterization in water a 5 µm parylene passivation layer is subsequently coated on top of the Mg resonators.

Fabricated Mg structures consist in spiral split-ring resonators (S-SRRs) (Fig. 2a) [4]. Such geometries enable maximizing the capacitance and thus minimize the resonance frequency for a given size of the resonator while keeping the geometry on a single layer. Figure 2a shows a typical fabricated micro-resonator. Figure 2b shows test structures aiming to validate 4 µm resolution and 0.5 aspect-ratio. S-SRRs are characterized by measuring the change of transmitted power when the resonator is placed 300 µm above a coplanar waveguide (CPW) (Fig. 3). For the characterization in water, the CPW is protected by a 5 µm Mylar film. Figure 4 shows the resonance frequencies of different S-SRR devices in air and in water. As shown in Table 1, the measured values agree well with the simulated resonance frequencies (f_0) and quality-factors (Q). The time for a 2 µm thick resonator to be fully dissolved in DI water is 75 minutes. Transfer to a biodegradable substrate will be implemented adopting a similar strategy as in ref. [5]. In conclusion, we successfully fabricated bioresorbable frequency-selective Mg micro-resonators using a new and robust fabrication process based on IBE. This work is a significant step towards the fabrication of biodegradable microwave resonators for thermal therapy and triggered drug release [6].

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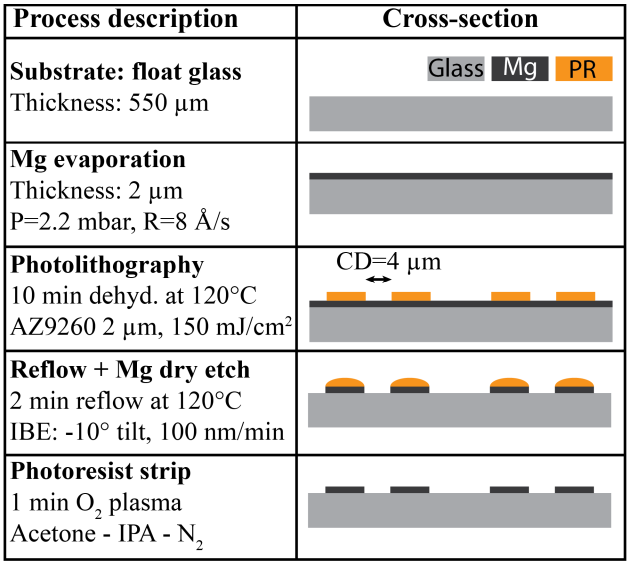


Figure 1: Process flow for the fabrication of Mg microstructures by IBE avoiding exposure to aqueous media.

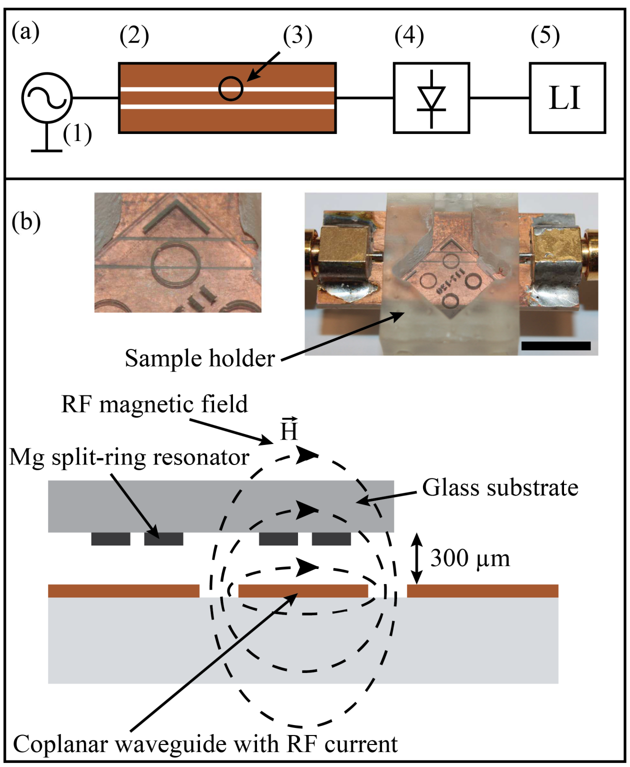


Figure 3: S-SRR characterization setup. (a) The setup consists of a signal generator (1), a coplanar waveguide (2), a S-SRR (3), a power detector (4) and a lock-in amplifier (5). (b) Schematic cross section view of the characterization setup. The S-SRR is placed 300 µm over the coplanar waveguide. The center of the resonator is aligned vertically with the side of the waveguide in order to maximize perpendicular magnetic field. Insets show top-view photographs of the coplanar waveguide with the resonator on top of it. Scale bar is 1 cm.

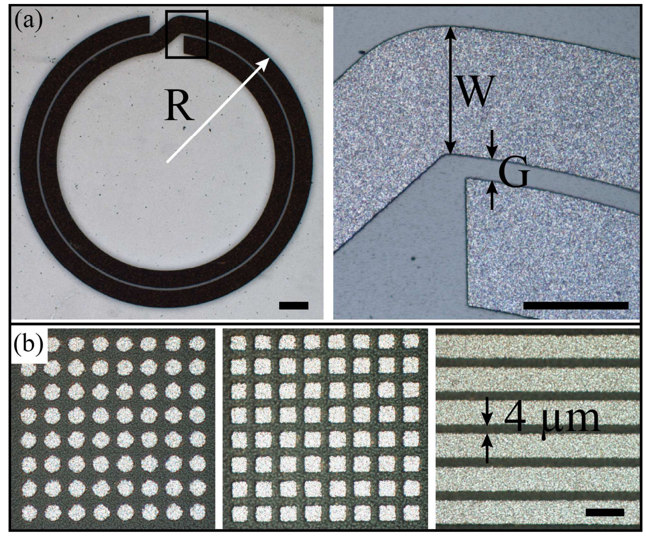
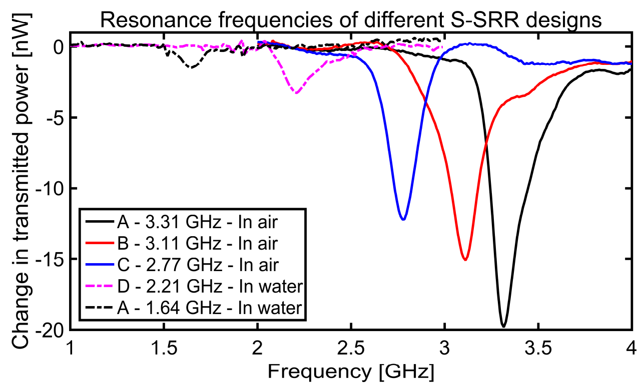


Figure 2: Fabricated Mg microstructures. (a) Typical spiral split-ring resonator with a close-up view of the gap between each turn of the coil. Scale bars are 100 µm. (b) Circles, square and lines demonstrating 4 µm resolution and 0.5 aspect ratio. Scale bar is 20 µm.



	R [µm]	W [µm]	G [µm]
A	1280	160	20
B	1280	160	10
C	1280	80	10
D	1000	120	15

Figure 4: Resonance frequency measurement of different S-SRR designs in air and in water.

Table 1: Comparison of measured and simulated resonance frequencies and quality-factors for three S-SRRs geometries in air.

	Measured value		**FEM (COMSOL)**		**Analytical model ([4])**	
	f_0 [GHz]	**Q**	**f_0 [GHz]**	**Q**	**f_0 [GHz]**	**Q**
A	3.31	16	3.41	26	3.41	27
B	3.11	15	3.14	24	3.12	26
C	2.77	16	2.77	18	2.78	15