Remote Monitoring of Absorbable Cardiovascular Stents using mm-waves

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***Abstract*—In this paper, we propose a corrosion monitoring scheme for the absorbable cardiovascular stents composed of magnesium alloys. We show that the structural integrity of such mesh-type tubular stents can be evaluated using millimeter-scale electromagnetic waves. With the passage of time, the strut thickness of the stent decreases due to corrosion which is subsequently observed in terms of a frequency shift in the simulated scattering response.**

biodegradable cardiovascular stents, non-destructive evaluation, millimeter waves

I. Introduction

Cardiovascular disease (CVD) is the leading cause of death worldwide, and it accounted for an estimated 30% of all deaths in the year 2013 globally [1]. Clogging of the heart vessels is the biggest factor responsible for the development of the CVD. These days, it is a common clinical practice to reopen the heart vessels through balloon angioplasty, and place a mesh-type metallic scaffolding tube called a stent to reinforce the vessel walls. However, due to the long-standing presence of a metallic foreign object in the form of a stent, serious health complications arise chief among which is the reclogging of the vessels in the long term, especially in the vicinity of the stent. From a medical perspective, an ideal stent would be the one that serves its purpose of reopening and stabilizing the heart vessels and then disappear [2]. The biodegradable stents precisely offer such a possibility where the scaffold structure completely corrode away after performing the reinforcement of the heart vessel walls [3].

Biodegradable polymers and metals is an active research area nowadays. Due to the vastly superior mechanical properties, metals are therefore more suitable for medical implants [4]. Among metals, iron, zinc and magnesium-based alloys have shown promise for degradable stent applications, but as of today, only Mg-based biodegradable stents have been clinically tested in humans [5], [6]. The mechanical properties of Mg such as elasticity closely resemble the human bone [7] and with the help of alloying, further attractive characteristics can be achieved. More importantly, Mg can be metabolized by the body through the chemical reaction,

$$\mathrm{Mg} + \mathrm{H_2O} \longrightarrow \mathrm{Mg^{2+}} + 2\,\mathrm{OH^-} + \mathrm{H_2}$$

and is also vital in maintaining a healthy heart, and given the weight of a typical coronary stent is in the range of 3 mg–5 mg, the release of Mg ions is unlikely to cause any adverse toxic effects.

One of the biggest engineering challenges presented with the use of an absorbable stent is ensuring its structural integrity until the stent completely breaks down by being metabolized in to the bloodstream. In view of this, it is critical to monitor the stent and its absorption due to corrosion need, preferably through non-invasive means. In this paper, we propose an electromagnetic monitoring scheme that monitors the structural integrity of a biodegradable stent using millimeter waves (mm-waves). Compared to the microwave wave imaging, mm-wave provides higher spatial resolution. On the other hand, mm-waves can penetrate deeper into the human tissue compared with the optical frequency counterparts. Using full-wave 3D electromagnetic simulations, we show that the stent corrosion can be correlated to the frequency shift in the backscattering properties.

II. Methodology

We simulate a three dimensional model of a magnesium cardiovascular stent and monitor the corrosion through the millimeter electromagnetic backscattering. The simulations were carried out using the frequency domain solver of CST Microwave Studio. For a stent composed of a mesh of wires as shown in Fig. 1, the corrosion only affects the cross-sectional

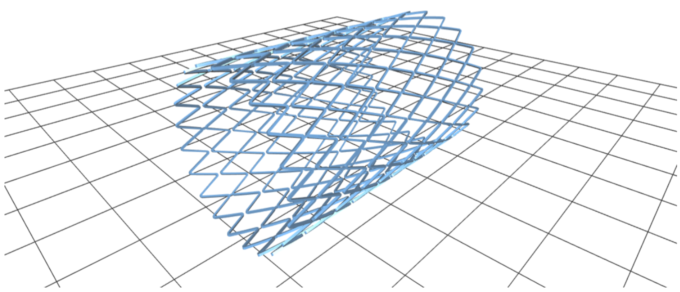

Fig. 1. An open stent design in the expanded state

area of the wire and it is independent of the length of the structure [8]. The corrosion rate P of a wire with an initial radius r_0, at any given time t is,

$$P = \frac{\mathrm{d}r}{\mathrm{d}t} = \frac{r_0 - r(t)}{t} \tag{1}$$

where $r(t)$ is the wire radius at time t. In this paper, we used the *Open stents* CAD model which is fully customizable due to its inherent parameterization [9]. The stent length was set to 25 mm with the diameter in the expanded state equal to 4 mm. The stent strut thickness was initially set to 0.2 mm. Using (1), a penetration corrosion rate of $1.94\,\mathrm{mm\,yr^{-1}}$ for a magnesium alloy (AZ31) [10] would leave behind 0.125 mm thick wire after a 2 weeks period, and considering P as uniform, the structure will be completely absorbed after 6 weeks. We simulated the scattering response by progressively decreasing the strut thickness of the stent. To reduce the computational cost, we assumed the background material as free space. A point dipole was used to create the excitation signal.

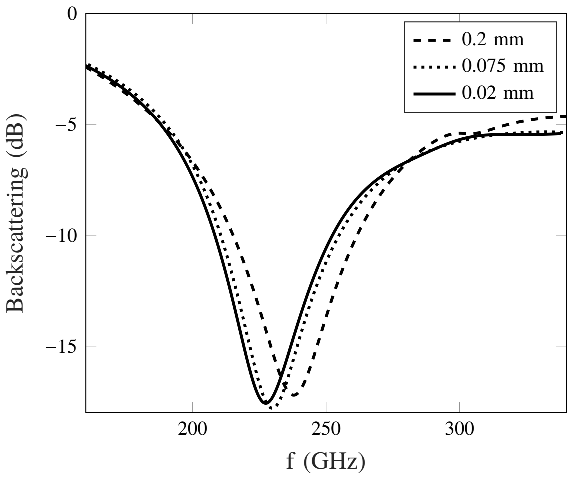

Fig. 2. Backscattering for different strut thicknesses

III. Results and Discussion

Figure 2 shows the backscattering from the open stent model described earlier with varying thicknesses. Although it is well known that the resonant frequency of a dipole antenna is only dependent upon the length, however, the electromagnetics of meshed structures such as the stent is complex due to its partially transparent nature to the wave. Table I lists the resonant frequencies extracted from Fig. 2, and interestingly, a linearly decreasing frequency shift is observed as the stent is progressively corroded.

TABLE I
Effect of thickness on the resonant frequency

Thickness (mm)	Resonant Frequency (GHz)
0.2	237.2
0.075	230.2
0.02	227

IV. Conclusion

In this paper, we presented a non-invasive technique to progressively monitor the degradation of a magnesium based bio-absorbable cardiovascular stent using millimeter waves. The proposed frequency range can provide sufficient spatial resolution and penetration without applying any radiation damage to the tissue. The fast corrosion rate of magnesium based biomaterials points to great potentials in designing cardiovascular stents. However, question marks on the structural integrity and corrosion remnants have restricted their popularization. In this preliminary report, we addressed some of these concerns by proposing a corrosion monitoring scheme that can non-invasively track the structural degradation by observing the frequency shift in the electromagnetic scattering.

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