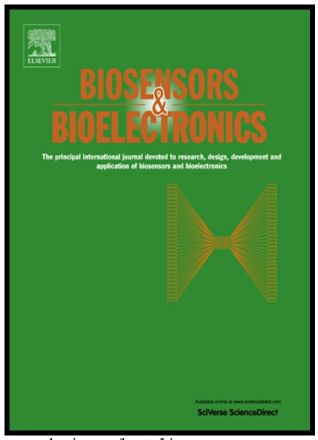

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Recent advances in metamaterial split-ring-resonator circuits as biosensors and therapeutic agents

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ABSTRACT*:* Potential applications of thin film metamaterials are diverse and their realization to offer miniaturized waveguides, antennas and shielding patterns are on anvil. These artificially engineered structures can produce astonishing electromagnetic responses because of their constituents being engineered at much smaller dimensions than the wavelength of the incident electromagnetic wave, hence behaving as artificial materials. Such micro-nano dimensions of thin film metamaterial structures can be customized for various applications due to their exclusive responses to not only electromagnetic, but also to acoustic and thermal waves that surpass the natural materials' properties. In this paper, the recent major advancements in the emerging fields of diagnostics (sensors) and therapeutics involving thin film metamaterials have been reviewed and underlined; discussing their edge over conventional counterpart techniques; concentrating on their design considerations and feasible ways of achieving them. Challenges faced in sensitivity, precision, accuracy and factors that interfere with the degree of performance of the sensors are also dealt with, herein.

KEYWORDS**:** metamaterial; microwave; terahertz; plasmon; electromagnetic; dielectric; refractive index; resonance

1) Introduction

Sensors are of vital importance to several applications, especially for their development for chemical and biosensing purposes. Electrical investigation of biological materials has been performed over the past century, using both conventional electrodes and microelectrodes. Owing to well-established micromachining techniques, various kinds of biosensing mechanisms have been developed based on the principle of surface plasmon resonance (SPR)(Dostálek et al., 2005),(Oh et al., 2004), fluorescence(Pickup et al., 2005),(Viveros et al., 2006), electromechanical transduction(Fritz et al., 2000),(Lee et al., 2004), nano-materials(Guan et al., 2005),(Alivisatos, 2004) and other electrochemical(Murphy, 2006),(Wang, 2006) or other physical processes, such as quartz crystal microbalance (QCM)(Janshoff et al., 2000), cantilevers etc.(Daniels and Pourmand, 2007),(Ziegler, 2004). These biosensors, though being precise and accurate in detection, face significant limitations as some require laboratory based methods which make these systems more complex with highly sophisticated equipments involving multistep extraction/purification of samples(Singh et al., 2014) with intensive sample preparation and off-site post-verification, features which make these techniques both cumbersome and expensive. Biosensors in general have been developed on two basic aspects: one is based on an extremely accurate and precise detection principle like an SPR and a micro-cantilever biosensor; whereas the other is based on developing a low-cost, on-site sensing device such as disposable biosensors(Abayomi et al., 2006),(Muhammad-Tahir and Alocilja, 2004). Among these, the latter concept of biosensors has received more attention because of its simple and easy detection ability despite being less accurate along with lesser sensitivity compared to other sensing techniques. Micro-calorimeter falls under the latter type of biosensors which has a simple and easy detection scheme(Winter and Höhne, 2003),(Sun et al., 2011) however, with a drawback of complex fabrication. Conventional sensors also pose issues of selectivity; which happens to be an equal challenge for both types of sensors. With traditional sensing procedures showing such limitations, efforts are on to explore some un-conventional methods with the utilization of some alternative possible sensing techniques like those which are metamaterial based; because of the extraordinary properties shown by these thin film metamaterial configurations. This has been an offshoot of the recently explored unconventional sensing procedures using nano-structured materials, which are being explored due to their ability to "see", "manipulate and "arrange" micro-molecules on a "self-assembled" route, creating a path for making nano-structured artificial patterns a reality in the submicron regime. Based on the fundamental idea that a compact form factor can offer considerable enhancement in performance (Bhansali and Vasudev,

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