Array Metasurfaces for Biomedical Sensing at Infra-Red Wavelengths

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ABSTRACT

Detection and identification of biomedically significant molecules is an important application in infra-red (IR) spectroscopy. This presentation will consider some of the significant features of the different alternative building-block elements that can be used in array metasurfaces for enhanced detection sensitivity. The presentation will also address techniques and issues associated with the deposition and localisation of biological and organic chemical molecular material for detection and measurement using IR spectroscopy.

1. INTRODUCTION

The detection and identification by optical methods of small quantities of biologically and medically important molecular species has become an established spectroscopic technique. Delivery via micro-fluidic channels and deposition from solution of various molecules onto an appropriately patterned surface can provide the basis for infra-red spectroscopy that performs the required detection and identification of particular species. In the literature, this technique is often called surface-enhanced infra-red absorption (SEIRA) spectroscopy – and it can be used to establish the presence of characteristic molecular bond resonances that occur in the mid infra-red part of the spectrum. The patterned surface that delivers the desired enhancement of detection sensitivity typically consists of an array of optically resonant thin-film metallic or dielectric structures realised on a dielectric substrate. Because of the sub-wavelength scale of the size of the elementary structures and their spacing, the patterned surface may be termed a metasurface.

2. METASURFACE ARRAY PROPERTIES AND BIOMEDICAL SENSING

Although the spacing between the array elements is often periodic, that is not an essential feature for the purpose of spectroscopic investigation, since the reflection, transmission and absorption spectra of the array are predominantly characteristic properties of the individual elements. Not all elements in the array forming a metasurface are required to be identical, so that several different basic elementary resonators can be repeated within the total array, allowing several different target central wavelengths to be addressed simultaneously. However sufficiently close packing of the elements in a metasurface array typically broadens the resonance spectrum through mutual coupling effects.

Well-known examples of 'interesting' molecular bond-resonances include carbon-hydrogen (e.g. methyl) and carbon-oxygen (e.g. carbonyl) bonds. Particular combinations of bond resonances can then be used to identify the molecules present – via molecule-specific signatures. With appropriate surface preparation, the biological/organic molecules of interest can be localized on the elements of the metasurface array. Lithographic processes such as electron-beam lithography (EBL) and deep-ultraviolet (DUV) lithography can not only be used in defining the metasurface patterning, but also for defining the nano-scale regions where organic material (most obviously polymeric resist-type materials) is deposited. Molecular species that are of interest for quantitative sensing include organic, non-biological, molecules such as octadecanethiol (ODT) and poly-methyl-methacrylate (PMMA). Molecules of specifically biomedical interest include hormones such as estradiol. Because of their possible presence in significant amounts in common foodstuffs such as milk, hormones like estradiol are also relevant in environmental sensing and for food safety.

Arrays of various different basic resonant 'atoms' can be produced lithographically in thin metal films that have been deposited on dielectric (e.g. silica glass) substrates. A variety of elementary structures have been described in the literature – including asymmetric split H-shaped (ASH) structures [1], single-gap split-ring resonator (SRR) structures [2, 3] and double-gap asymmetric split-ring resonator (ASRR) structures [4-6]. ASH structures are of particular interest because of their ability to operate effectively in orthogonal polarisation situations. ASRR structures have the interesting feature of exhibiting both transmission/reflection resonance and an absorption resonance that can be described as a trapped-mode. Similar trapped-mode resonances should be observable in other forms of circularly or even elliptically-shaped resonators, with appropriately structured illumination.

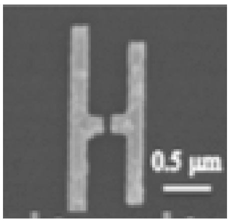

Figure 1(a). Image of a single ASH array element realised in gold thin-film on dielectric substrate.

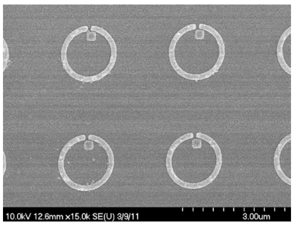

Figure 1(b). Several SRR array elements, with lithographically defined resist squares for location sensitivity probing.

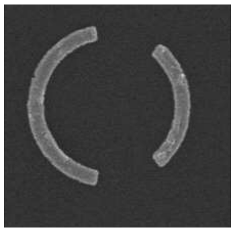

Figure 1(c). Image of a single ASRR array element realised in gold thin-film on dielectric substrate.

3.CONCLUSIONS

Array meta-surfaces can be generated using a variety of elementary building blocks realised on dielectric substrates. This presentation considers three alternative patterns that are of interest for applications in biomedical sensing. The use of meta-surfaces can greatly enhance the sensitivity of the molecular detection process.

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