Tunable Leaky-Mode MEMS Filters for Multispectral Imaging Applications

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Abstract—When an incident electromagnetic wave is properly coupled to a waveguide’s leaky eigenmode by a subwavelength grating, a guided-mode resonance takes place. This phenomenon can manifest itself as sharp, high quality resonances in the reflection spectra. Since these resonances are highly sensitive to the device structural parameters (grating thickness, period, and filling factor), a tunable resonance can be implemented if one or more of these parameters are suitably varied. In this paper, the micro-electro-mechanical system (MEMS) concept is applied for tuning the spectral response of resonant filters through mechanical microscale alteration of the grating profile. We provide numerical solutions based on exact electromagnetic models of MEMS-tuned resonance gratings designed with common materials. Computed results for an example tunable element with 6.0 μm period and 2.4 μm thickness show MEMS tuning of ~3.4 μm in the ~9-12 μm band with ~100 nm resonance linewidth. These elements are promising candidates for MWIR (3-8 μm) and LWIR (8-15 μm) multispectral imaging applications.

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1. INTRODUCTION

As the term implies, multispectral imaging refers to a combination of spectroscopy and photography. By using rapidly tunable filters and two-dimensional (2D) image planes such as those provided by charge-coupled device (CCD) detectors, data sets containing spatial (x, y) and spectral information are acquired. The resulting spectral image cubes contain intensity and wavelength (λ) data at each pixel in the 2D image [1]. Under time-varying conditions, the data cube would be multidimensional in (x, y, λ, t) space. Hyperspectral imaging is a similar concept principally differentiated from multispectral imaging in that many more wavelengths and narrower spectral passbands are employed. Thus, in multispectral imaging, relatively few wavelengths are used to carry the spatial information whereas in hyperspectral imaging, the number of wavelength channels may reach ~100 [2]. Each of these methods is connected with a plethora of useful applications. Examples include spatio-spectral diagnostics in agricultural crop management, true-color night vision, forensics, and archaeology and art [1]. In medicine, hyperspectral in vivo diagnostics of tissue may avoid excision and permit in situ analysis [2]. Its application to real-time guidance in surgery is promising [2].

The capability of the tunable filters central to these spectral imaging methods defines the quality of the data sets collected. Gut lists principal attributes of ideal tunable filters and describes examples of filters employed to date [1]. Among these, tunable liquid-crystal and acoustooptical filters represent two prominent device classes [1, 2]. The former is based on stacks of birefringent liquid crystal plates integrated with polarizers whereas the latter is diffractive in nature.

The objective of the present contribution is to introduce a new tunable filter concept for potential application in multispectral and hyperspectral imaging systems. In short, we employ a resonant waveguide grating supporting leaky modes that is tuned by micro-electro-mechanical (MEMS) means. We begin the paper by summarizing the physical basis for this class of tunable filters. Then, we provide numerical spectral characteristics of resonance elements based on exact electromagnetic models of the devices with representative materials. We investigate theoretically the operation of MEMS-tunable resonant elements. In particular, we provide numerical results for a fixed transmission filter, a tunable reflection filter mounted on a low-index substrate, and then contrast its tuning capability with that of a classical Fabry-Perot filter in the LWIR band. Further examples of guided-mode resonance (GMR) tunable devices for multispectral imaging applications quantify their tunability relative to the mechanical displacement as well as spectral bandwidths and associated sideband levels. We envision these tunable filters finding use in aerospace multispectral imaging applications such as multi-channel thermal imaging, landscape temperature mapping, remote sensing, multispectral IR target recognition and in other areas.

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