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Subwavelength Structured Narrow-band Integrated Optical Grating Filters

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Abstract

A unique type of narrow-band integrated optical filter is investigated based on embedding a subwavelength resonant grating structure within a planar waveguide.

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1.0   Introduction

A unique type of narrow-band integrated optical filter is investigated based on embedding a subwavelength resonant grating structure within a planar waveguide. Current integrated narrow-band optical filters are limited by their size, density of devices that can be produced, overall performance, and ability to be actively altered for tuning and modulation purposes. In contrast, the integrated optical filters described in this work can have extremely narrow bandwidths - on the order of a few angstroms. Also, their compact size enables multiple filters to be integrated in a single high density device for signal routing or wavelength discrimination. Manipulating any of the resonant structure's parameters will tune the output response of the filter, which can be used for modulation or switching applications.

Previous work on subwavelength resonant grating structures have concentrated solely on large planar surfaces (not confined to a waveguide for an integrated optical device). A subwavelength grating structure is a zeroth order diffraction grating that can be represented by an effective uniform homogeneous material (n_{eff}).[1-3] Under particular structural configurations ($n_o < n_{eff} > n_2$), subwavelength structured surfaces exhibit a resonance anomaly which results in a strong reflection in an extremely narrow bandwidth.[4,5]
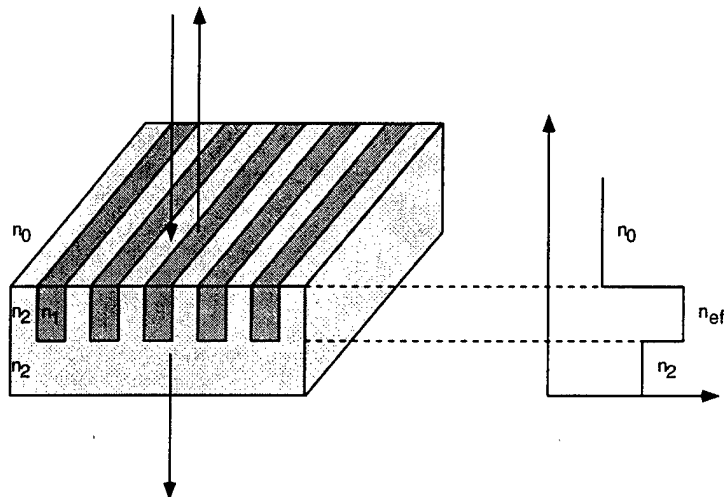

Figure 1 - Planar Surface Subwavelength Resonance Filter

This resonance phenomenon occurs when a surface propagating field is trapped within the grating region due to total internal reflection. If this trapped field is coupled into the mode of the effective waveguide, the field will resonant and redirect all of the energy backwards. This resonance effect results in a total reflection of the incident field from the surface, which is extremely sensitive to wavelength (narrow-band reflection filter).

The following example demonstrates the performance of a planar surfaced resonant grating structure. The parameters of the structure are $n_o = 1.0$, $n_1 = 1.52$, $n_2 = 1.62$, $d = 1032nm$, and $\Lambda = 1017nm$, where d is the thickness of the resonant region and Λ is the period of the grating. Figure 2 illustrates the response of the resonant filter. Note that the bandwidth of the filter is on the order of a few angstroms.
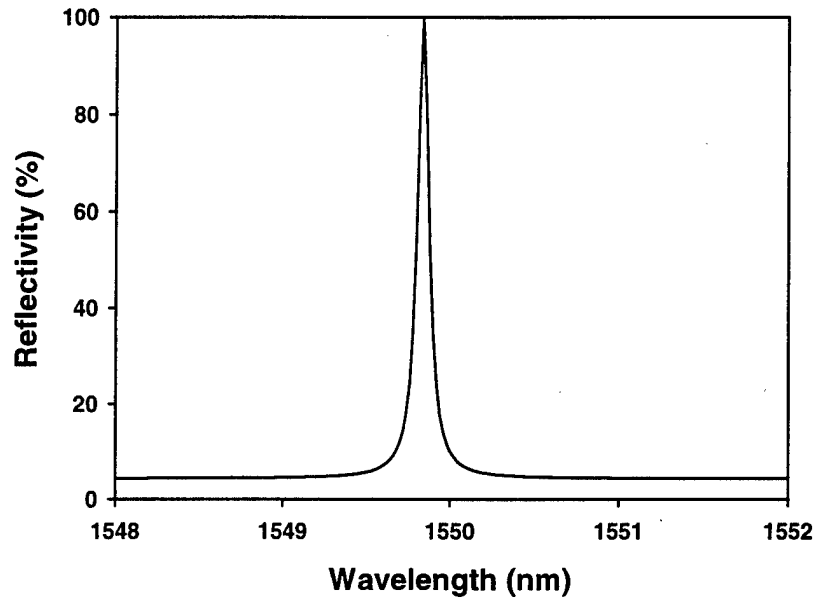

Figure 2 - Spectral response of the designed resonant filter ($\lambda_{resonance} = 1549.8nm$)

2.0   Device Description

The device investigated is based on embedding a subwavelength resonant structure within a planar waveguide to create an integrated narrow-band optical filter. Figure 3 provides a conceptual illustration of an embedded resonant structure within a planar waveguide.
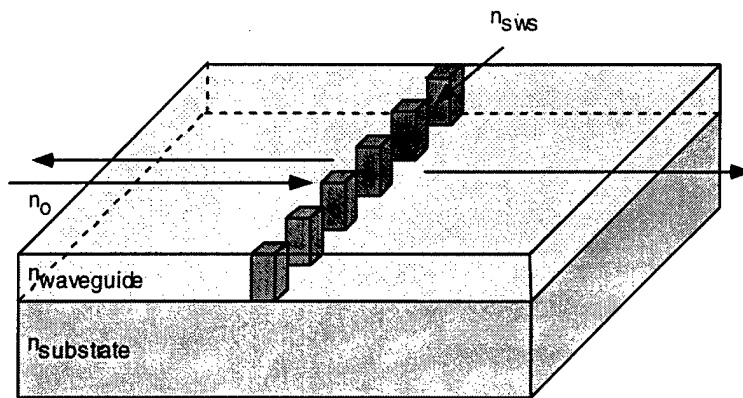

Figure 3 - Embedded Subwavelength Resonant Structure within a Planar Waveguide

In order to create a resonance effect, $n_{sws} > n_{waveguide}$, where n_{sws} is the refractive index of the subwavelength structured elements and $n_{waveguide}$ is the refractive index of the waveguide region. Also, in order to propagate the field within the planar waveguide region, $n_o < n_{waveguide} > n_{substrate}$.

Key Features:
1) <u>Minimal sideband reflections</u>. Since the resonant structure is buried within a waveguiding region, both the input and output regions of the resonant filter have the same material characteristics. Therefore, by designing the filter thickness to be approximately ½ wavelength thick, an incident field will experience minimal or no Fresnel reflections away from the resonance peak.

2) <u>Spatial control</u>: Resonant structures can be placed at a particular angle with respect to the incident field to redirect the resonant energy to another portion of the planar waveguide.

3) <u>High Packing Density</u>: The resonant structure is thin (~ ½ wavelength thick) and thus allows for a high packing density where multiple resonant filters are produced in a single planar waveguide device to perform a number of functions. Each filter can be designed for a particular wavelength, enabling the separation of a multi-wavelength input optical signal. Crossed resonant structures (i.e. two or more resonant structures which cross each other) can also be used with minimal cross-talk between structures.

4) <u>Tunability</u>: Manipulating any of the parameters of the resonant structure (angle of incidence, refractive indices, grating spacing, grating period, grating thickness) can result in a tuning of the output response.

Potential applications:
1) Wavelength division multiplexing / demultiplexing (WDM)
2) Tunable narrow-band integrated optical filter
3) Optical signal routing
4) Integrated optical modulator
5) Integrated optical switch
6) Spectroscopic analysis
7) Biological and chemical integrated optical sensors
8) Optical computing

3.0   Conclusions

A unique type of narrow-band integrated optical filter is being investigated based on embedding a subwavelength resonant grating structure within a planar waveguide. These integrated optical filters offer several advantages over existing filter technologies, and have the potential to play a significant role in future integrated optical systems. A prototype device is currently being constructed for operation near 1550nm.

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