Modal representation and normalized scaling rules for ultra narrow-band reflection from a 1D binary corrugation

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Summary

A 1D, high index contrast subwavelength binary corrugation on a low index substrate may under normal incidence exhibit arbitrarily narrow band reflection. The conditions for its occurrence are given on the basis of the resonances and interference of two involved grating modes and a phenomenological representation of this effect will be proposed. Normalized heuristic analytical expressions are derived which identify exhaustively all possible structures exhibiting this effect.

Introduction

A 1D, high index contrast subwavelength binary grating suspended in air (Fig. 1(a)) exhibits under normal incidence arbitrarily narrow band reflection characterized by a huge field accumulation in the high index corrugation (Fig. 1(b)). This effect was first discovered numerically [1], then confirmed experimentally on a suspended silicon grating at THz frequencies [2]. It also appears in the case of low index substrates, for which a semi-quantitative phenomenological explanation was given on the basis of a waveguide mode representation whereby the grating couples the incident free-space wave to a guided mode while also causing intra-guide coupling between the two counter-propagating modes via an enhanced second order of the grating [3]. Since then, a number of R&D works have concentrated on the diverse reflection properties of high index contrast subwavelength binary corrugations ranging from ultra-wide band [4] to ultra-narrow band [5] characteristics. In particular, the analysis in [5] attributes the resonance sharpness to the resonance of a super-mode of the finite groove and wall structure, the super-mode being a particular combination of the two involved eigenmodes of the infinite groove and wall structure. The conditions for the occurrence of this very narrow-band reflection are however still to be stated. It is the objective of the present contribution to shed light onto this effect and also give its conditions in a closed analytical form encompassing all possible optogeometrical structures exhibiting it.

Discussion

The existence conditions write in three sentences and are represented by a single chart (Fig. 1(b)):

- The first grating mode involved (the fundamental TE_0 mode) experiences a Fabry-Perot resonance (FP) of order m_0 in the binary corrugation.
- The second mode involved (the first higher symmetric TE_2 mode) experiences a FP resonance of order m_2 in the same corrugation.
- The difference between the TE_0 and TE_2 Fabry-Perot orders $m_0 - m_2$ is equal to an even number (marked line-crossings in Fig 1(b))

All narrowband resonances in a high index grating can now be identified by their corresponding m_0 and m_2 indexes. Scanning the space of the normalized geometrical parameters for the above mentioned three conditions leads to charts connecting three of the normalized parameters by a two-dimensional surface (see e.g. Fig.1(d), depicting the required Λ/λ, r/λ and n for giving the narrowband resonance of order $m_0 = 3$ and $m_2 = 1$). Those surfaces can be described by polynomial expressions, allowing a very convenient and straightforward design of narrowband resonance gratings.

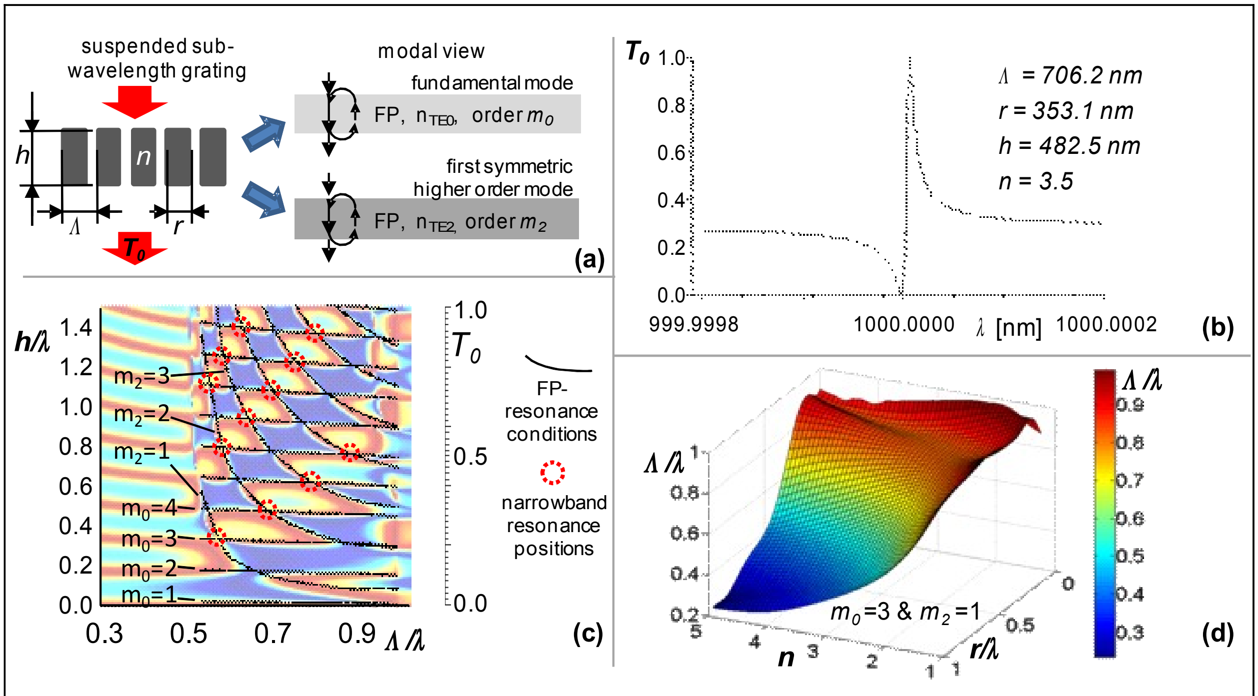

Fig. 1 **(a)**: Considered grating with parameter definition, **(b)**: example of extremely narrowband resonance, **(c)**: dependence of grating 0th order transmission T_0 on normalized grating period and height (with r/λ = 0.5, n = 3.5) superimposed with condition on h/λ for FP resonance of TE_0 and TM_0 (black lines) and indication of narrowband resonance positions, **(d)**: required normalized parameters Λ/λ, r/λ and n for the narrowband resonance with $m_0 = 3$ and $m_2 = 1$.

Conclusion

The electromagnetic nature of the ultra-narrow band reflection has been elucidated and the conditions for its occurrence are given exhaustively. As from here R&D work can concentrate on possible applications, which can be in ultra-sensitive biosensors, magnified nonlinear effects, ultra-narrow band filters for high NA beams, etc.

References

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