Design of near-field optical nanostructures for enhanced second-harmonic generation

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Abstract: We present optical nanostructure designs for enhancement of second harmonic generation based on near-field localization and phase matching effects, and analyze these nanostructures using a rigorous electromagnetic modeling tool.

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Recent advances in nanofabrication technologies have enabled the construction of a wide range of subwavelength optical nanostructures. In particular, periodic optical nanostructures made of nonlinear optical materials can be used to enhance nonlinear optical phenomena through two mechanisms: transverse localization and phase matching. In this paper we present nanostructure designs for the enhancement of second-harmonic generation based on these effects and analyze the enhancement of the second harmonic generation process using a rigorous electromagnetic modeling tool.

In previous work, we have described transverse localization in periodic optical nanostructures [1]. These nanostructures can be viewed as a coupled array of waveguides, with localization of the waveguide modes in the high refractive index regions of the structure. Due to this near field effect, we expect that significant enhancement of nonlinear optical phenomena can be achieved through spatial localization of the field in this type of nanostructure. In addition, by using a more sophisticated nanostructure having additional design degrees of freedom, it is possible to achieve phase matching between a fundamental and a second-harmonic propagating mode in the structure [2].

An example of such a structure is shown in Fig. 1a, consisting of periodic nanostructured GaAs ridges surrounded by air. The transmitted second harmonic intensity versus depth for both a bulk material and the nanostructure, calculated using a modified Rigorous Coupled-Wave Analysis (RCWA) technique [3] valid in the undepleted-pump limit, are shown in Fig. 1b [2]. The curves exhibit oscillatory behavior for both cases due to the Fabry-Perot cavity formed by the front and back interfaces of the nonlinear material. However, it can also be seen that significant enhancement of the second harmonic output is obtained with the phase-matched nonlinear nanostructure versus the bulk material.

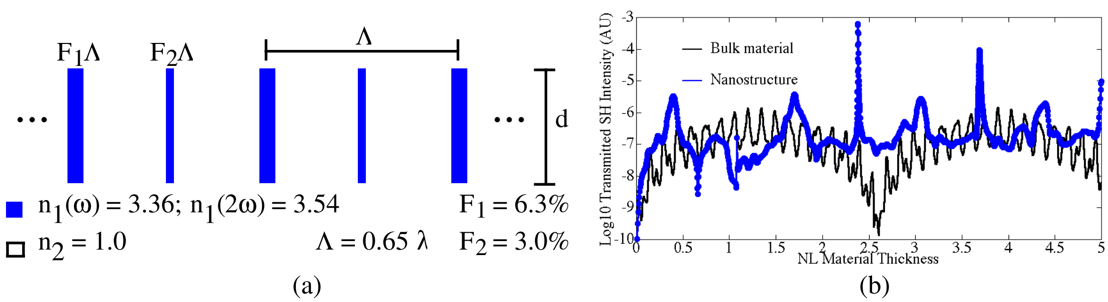
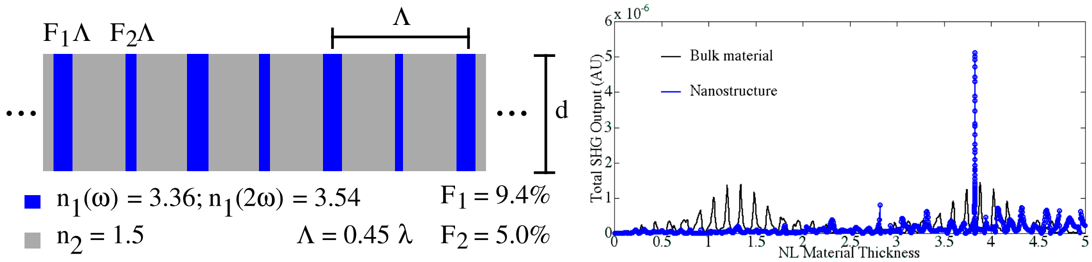


Fig. 1. (a) Schematic of enhanced SHG nanostructure having two differing grooves per grating period; (b) Transmitted second harmonic output (Log10 scale) versus nonlinear material depth for a bulk material and the nanostructure.

A second example SHG-enhancement device is shown in Fig. 2a, composed of periodic nanoscale layers of GaAs and oxidized AlAs. The transmitted second-harmonic intensity versus depth for this structure and the bulk material are shown in Fig. 2b. The enhancement from this structure is less dramatic due to the reduced field localization resulting from the lower refractive index contrast between the two materials. However, the fabrication process is simplified as the small fill factor ridges are achieved not by a difficult high aspect ratio etching step—as in the original design—but by epitaxially grown layers in which the thickness is easily controlled.



(a) (b)

Fig. 2. (a) Enhanced-SHG nanostructure composed of GaAs and oxidized AlAs; (b) Transmitted second harmonic intensity versus nonlinear material depth for a bulk material and the nanostructure.

These results illustrate the application of optical nanostructures to enhance nonlinear optical phenomena, specifically second harmonic generation. Due to the design degrees of freedom provided by a nanostructure composed of two or more constituent optical materials, it is possible to achieve both transverse localization and phase matching concurrently. An additional benefit of this approach is that the nanostructures are compatible with standard microfabrication techniques, facilitating their incorporation into integrated optical systems.

References:

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