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The New Operator Marching Method on Calculating the Electromagnetic Scattered Fields from the Periodic Structures

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Abstract. In this work, the operator marching methods based on the modified Neumann-to-Dirichlet (NtD) map are developed to calculate the scattered fields from the periodic structures, especially diffraction gratings with metallic material. For the grating structures coated with the metallic material, the modified NtD map operator marching scheme is numerically stable for calculating the electromagnetic scattered fields. The modified NtD map operators are constructed by the integral equation (IE) method in each homogeneous medium of the layered medium structures, and avoid the blow up of the condition numbers from the challenging metallic material with the complex refractive index. For the calculations of the scattered fields from the diffraction grating structures, the modified NtD map operator marching method takes advantage of the periodic structure features, and avoids the calculations of the complicated quasi-periodic Green's function. Numerical results demonstrate that the proposed method achieves high accuracy and low computational workload for the scattered fields from both the dielectric and metallic diffraction grating structures.

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Key words: Periodic structures, wave propagation problem, modified Neumann-to-Dirichlet map, integral equation method.

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1 Introduction

Periodic structures have special electromagnetic properties which are important in modern optics applications, such as bandgap, surface plasmon polariton. For example, photonic crystals (PhCs) [1], with a period on the optical wavelength scale, have bandgaps that inhibit spontaneous emission phenomenon. Diffraction gratings [2] have unusual abilities to manipulate light due to their periodic surface patterns. In recent years, metallic gratings [3] have attracted much attention for their extraordinary optical transmission phenomenon. This effect could be exploited in some important technological fields such as photolithography or near field microscopy [4]. An another unusual phenomenon, named as the surface plasmon polariton (SPP), has also drawn rather considerable interests in recent years. Briefly, a SPP is a surface electromagnetic wave that propagates along the interface between a metal and a dielectric medium [5–7]. It is an intrinsical excitation whose electromagnetic field decays exponentially with distance from the surface. Most SPPs are shorter in wavelength than the incident light, resulting in lighter spatial confinement and higher local field intensity. In contrast to conventional waveguides, the fields of SPP's both sides are evanescent in space. For SPP-based devices, the most critical part is the plasmonic material, which in most cases are metals. Since the electromagnetic field of a SPP decays fast, it cannot be observed in usual experiments unless it is transformed into light. Therefore, it is necessary to find a simple, efficient and accurate numerical method to investigate the propagation behavior and SPP effect of waves through periodic structures with metallic materials. To utilize these periodic structures efficiently, several computational procedures are developed to analyze the electromagnetic scattered fields from the periodic structures, such as the FDTD, FEM and IE methods.

Over the last few years, many rigorous numerical methods [8–19] have been developed for the nano-periodic structures. Among these methods, some are general, such as the finite-difference time-domain (FDTD) method [20], which can be used to analyze various aspects of PhCs and gratings. But its accuracies and efficiencies are often limited. Other special methods, such as the integral equation (IE) method [21], are often more efficient. The IE method translates the problems into a system of integral equations on the boundaries of the homogeneous domain of the gratings. However, it has its own limitations with the quasi-periodic Green's function involved [22], which leads to expensive calculation expense. In our previous work [23,24], we have developed a Dirichlet-to-Neumann (DtN) map method for scattering problems from periodic photonic crystals. The DtN map relates the wave field components to their normal derivatives on the boundary cell and thus restricts the calculations to the edges of the unit cells. For diffraction grating problems, the Neumann-to-Dirichlet (NtD) map method takes advantage of the grating features are very efficient. The NtD method divides one period of the layered grating structures into several homogeneous sub-domains, and then computes the NtD maps for these homogeneous sub-domains by the boundary integral equation method. Unlike the existing integral equation method, the NtD map method avoids the calculations of the quasi-periodic Green's function.