ISSN 0735-2727, Radioelectronics and Communications Systems, 2015, Vol. 58, No. 5, pp. 201–211. © Allerton Press, Inc., 2015.
Original Russian Text © O.V. Shapoval, 2015, published in Izv. Vyssh. Uchebn. Zaved., Radioelektron., 2015, Vol. 58, No. 5, pp. 18–29.

Scattering of Light Waves by Finite Metal Nanostrip Gratings: Nystrom-Type Method and Resonance Effects

O. V. Shapoval

Usikov Institute of Radiophysics and Electronics
of the National Academy of Sciences of Ukraine, Kharkiv, Ukraine
e-mail: olga.v.shapoval@gmail.com

Received in final form September 25, 2014

Abstract—Efficient and rapidly convergent numerical algorithm for the simulation of the scattering of light waves by a finite gratings consisting of thin (thinner than the wavelength in the free space) metal nanostrips is presented. The model is based on the utilization of generalized boundary conditions (GBC), which allow one to exclude from consideration the field inside each strip and to reduce the two-dimensional boundary problem to one-dimensional systems of singular/hypersingular integral equations (IE). The obtained IE are solved numerically using the Nystrom-type method and the quadrature formulas of interpolation type, that provides guarantee convergence and controlled accuracy. The article presents the results of characteristics calculations for optical scattering and absorption by the gratings, which consist of silver nanostrips, as dependences on the width and on the thickness of the strips, and on the grating period. The nature of resonance phenomena has been investigated, namely the article presents the analysis of intensive optical scaterring and absorption in the case of excitation of plasmonic modes (plasmons) and of grating modes, which are induced by the periodicity.

DOI: 10.3103/S0735272715050027

1. INTRODUCTION

Nanoscale materials, devices and technologies is permanently developing and expanding range of science and industry, which rapidly generates new areas, such as nanophotonics and nanooptics. Resonance effects in the scattering and absorption of light waves by metal nanoobjects are associated with surface plasmon resonances and have a wide range of practical applications. For example, in the case of biosensors designing the plasmon effects allow one significantly improve the efficiency of detection, identification and diagnostics of biological objects by increasing the intensity of fluorescence.

Due to modern technologies of sputtering, deposition and etching the nanowires and thin nanostrips made of precious metals (silver, gold) have permanently become a part of many devices for terahertz and optical wave bands (for instance, nanoantennas and biosensors) [1–5]. Periodic gratings of nanowires and nanostrips attract particular attention. This is connected with the newly discovered phenomena of anomalous reflection, transmission, radiation and amplification of the near field [3–6]. Such phenomena are observed near the so-called Rayleigh anomalies for the corresponding infinite gratings [6] and, in the most general case, they possess the form of Fano-type resonances in the spectra of corresponding characteristics.

The techniques for the numerical simulation of optical properties of nanostrips include the techniques of volume [7] and boundary integral equations (IE) [8]. Boundary IE are more efficient due to the fact that it is necessary to discretize only the strip's contour instead of its volume. Secondly, the boundary IE often have smooth or integrable kernels, which ensures a more reliable discretization. It should be noted that the number of unknown quantities, even when calculating characteristics for one nanostrip, is equal to several thousand for the volume IE and it equals to hundreds for the boundary IE.

In contrast to [7, 8], in this paper the two-dimensional problems for scattering of electromagnetic waves by finite gratings made of thin silver strips in the optical range are studied by means of dual-sided generalized boundary conditions (GBC) [9] and they are reduced to systems of singular and hypersingular IE. They are solved by the Nystrom-type method with the utilization of quadrature formulas of interpolation type [10, 11].

Note that the Nystrom-type technique has recently attracted particular attention in the simulation of wave scattering by perfectly conducting and infinitely thin planar and curved strips. This article is related to the development of such a mathematical model, of the numerical algorithm for solving the problems of light