Paper

New method of numerical modelling of optical field transformation by inhomogeneous semiconductor layer with time-varying parameters

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Abstract — A time-domain model of a semiconductor layer with time-dependent inhomogeneous permittivity or conductivity is investigated by solving direct and inverse problems using a novel method, revealing a possibility of wavelength shifting and other desirable optical field transformation, as well as a remote diagnostics of fast time-varying inhomogeneous structures.

Keywords — optical field transformation, wavelength conversion, nonlinear phenomena in semiconductor.

Optical field transformation like wavelength conversion and others, being one of the main topics in optical communication, can be achieved with a number of methods. Recent research in this field turns toward all-optical wavelength conversion in semiconductor optical amplifiers using either cross-gain modulation, cross-phase modulation or four-wave mixing.

Media with time-varying parameters can also be used to obtain a desirable field transformation, and combination of temporal and spatial variations here give an extended possibility for it.

In the present paper we consider a model of the transforming structure as a finite 1D layer with arbitrary temporal and spatial (along one coordinate) dependencies of its permittivity or conductivity. Direct and inverse problems are considered, toward such structure synthesis and diagnostics.

A novel method, common for solving inverse and direct problems of electromagnetic field scattering on 1D finite structures with arbitrary temporal and spatial dependencies of their parameters (permittivity or conductivity), is proposed. Its schematic algorithm is shown in Fig. 1. It is based on integral equations for electromagnetic field obtained by evolutionary approach assuming that the nonstationarity starts at a certain time moment. Represent a conducting current function as an expansion into series of step-functions on spatial coordinate with transient coefficients like the following:

$$j(t,x) = \sum_{k=0}^{m} S_k(t)\ \theta(x-ak), \qquad (1)$$

where $m_{max} = Integer(vt/a)$ (maximum integer number of this ratio). It means that we divide the conducting current function into thin sub-layers in which it is homogeneous being however nonstationary (Fig. 2).

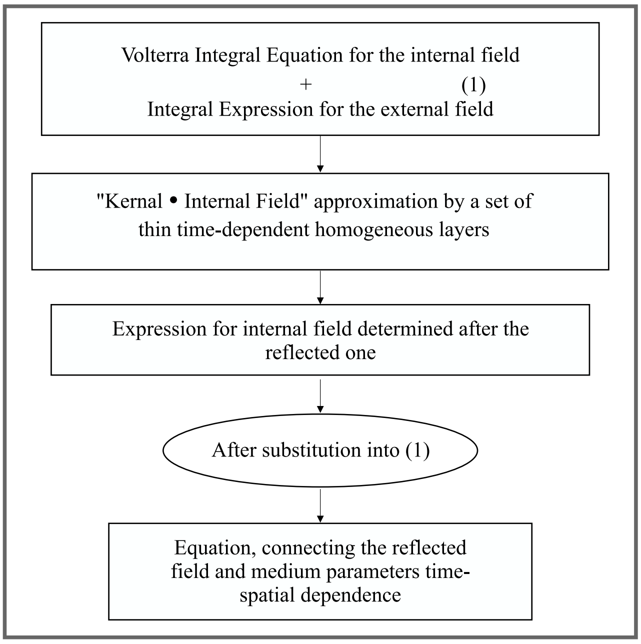

Fig. 1. Algorithm of the novel method common for solving the inverse and direct problems

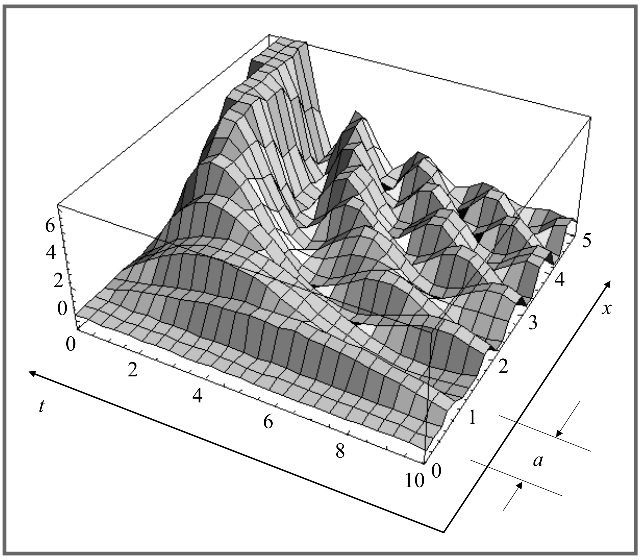

Fig. 2. Illustration of the current representation by homogeneous transient sub-layers

Then it is possible to obtain the internal field (that is the field inside the transient inhomogeneous medium) expression after the external one (the external region outside the scattering medium is assumed being stationary and homogeneous). After substitution of this expression into the initial integral equation for the internal field, we have an equation which connect the external field and the scattering medium parameters. This equation can be solved analytically for both inverse and direct problems. That is, one can obtain its exact solutions for the medium parameters temporal and spatial dependencies determined after the external field as well as for the external field determined after these parameters.

The solutions are represented as finite sums. The proposed method was realized in computer programs. Its convergence is rigorously proved due to the extension into the full series of orthogonal functions. Another its advantage is that it enables one to consider scattering of any incident fields on such transient inhomogeneous structures including harmonic waves, pulses and others. The inverse problems technique can be used for solving the problems of the structures synthesis to obtain a required scattered field as well as for diagnostic problems of retrieval of the scatter characteristics by the reflected field (remote sensing). In the latest case calculations showed that the used technique is stable to the input data noises being so a promising one for measurements processing.

Some special cases of the inverse and direct problems were calculated such as layered structures with time-dependent conductivity or permittivity, retrieval of the parameters providing the incident field frequency shift and others. As an example, calculated spectrum of the field reflected from quasi-periodical structure with temporal permittivity is presented in Fig. 3, showing a possibility to obtain high reflection not only at the incident wave frequency (the incident field was assumed as a plane harmonic wave) but also for a wide range of frequencies, forming so by reflection from such a structure not only waves of other frequencies but also optical pulses.

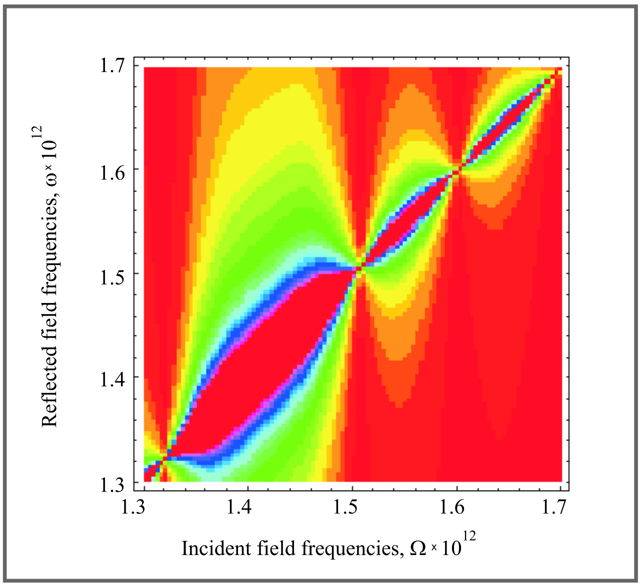

Fig. 3. Reflected field spectrum for transient structure for small *t*

Conclusions

The proposed new method for determination of transient 1D media parameters by the reflected field reveals a possibility of optical field transformation by structures like metal-dielectric-semiconductor diodes and pulse-induced temporal reflectors. Such an induced transient structure can be used as a field transformer for a wide range of medium properties, when considering field interactions with them. Theoretical modelling performed and consequent numerical modelling shows different possibilities of an incident field transformation by reflecting from such structures, like frequency shift, pulse collapse, etc.

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