

Numerical method solved in the Scilab program, for the analysis of a nonlinear mirror

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In the last few years, investigations into processes of global climatic change have demonstrated the primary importance of consideration of the atmospheric aerosol as a climate-forming component of the atmosphere. New methods and procedures of laser sensing of the atmosphere provide better information from the viewpoint of the accuracy of reconstruction of the sought-after atmospheric parameters. In this paper we present an analysis of a nonlinear mirror, which uses second harmonic generation as well as reverse process using SCILAB program.

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1. Introduction

The investigations of absorption properties of ambient aerosols carried out during the last 25 yr strongly suggest that the main absorbing component in the ambient aerosol in the shortwave spectral range is a fine aerosol fraction containing the so-called black carbon (BC) aerosol (soot), which is characterized by a weakly selective absorption spectrum. Other main components of the ambient submicron aerosol (sulfates, organic matter, water) absorb very poorly in the shortwave spectral range, meaning that BC (soot) is a dominate absorber of shortwave radiation. The coarse fraction of dust particles with sizes of more than 1 μm may somehow contribute to aerosol light absorption in the shortwave spectral range. The absorption coefficient of such particles is three orders of magnitude lower than that of the fine soot aerosol and, as noted by Hansen et al. [4], the share of the coarse fraction in aerosol absorption can reach 10 to 25% only during strong dust storms. Rosenberg came to a conclusion in his paper [6], that “The weakly-selective short-wave aerosol absorption is mainly due to an individual submicron subfraction composed of soot particles (predominantly trapped by nonabsorbing matter) with modal radius of about 0.02 to 0.03 μm and, probably, lognormal size distribution. Concentration of these particles widely varies approximately from 0.1 to 50 kg km^{-3} depending on the activity of anthropogenic and natural sources. Other aerosol fractions play a minor role in the shortwave absorption. In another words, radioactive and climatologic effects of aerosol (absorbing aerosol) are fully associated with its soot component that have to form the basis of model computations.”

New methods and procedures of laser sensing of the atmosphere provide better information from the viewpoint of the accuracy of reconstruction of the sought-after atmospheric parameters.

Measurements of the aerosol light absorption with the particles suspended in the atmospheric air, are carried out using the laser photoacoustic (PA) spectroscopy technique. Originally, the PA technique was applied to study the light absorption of high concentrations of artificial aerosols (cigarette smoke, diesel soot, etc.). The laser PA technique for the light absorption in the atmosphere has been developing since 1970.

In the 1980s, the availability of short pulses from titanium-doped sapphire (Ti:sapphire) lasers changed the way scientists investigate the physical world. With pulse durations in the femtoseconds, scientists essentially could take the equivalent of a still photo of extremely short-lived events, illuminating chemical interactions as they happened and, creating a new understanding of how materials are formed from molecular constituents.

By the mid-1990s, the need to make ultra-rapid lasers simpler to operate led to diode-pumped solid-state (DPSS) green pump lasers for the Ti:sapphire oscillators. These systems are still mainly for research activities in chemistry, physics, and biology, rather than industrial applications. Several nonlinear processes have been used to realize power-dependent reflection. Simulated Brillouin scattering, for example, provides power reflection, which may even exceed 100%, due to pulse compression [2].

In this paper we present a numerical method for the analysis of a nonlinear mirror, which uses second harmonic generation, as well as the reverse process, using a Scilab program. This device promises no frequency shift, has high durability and may have sub-picosecond time resolution.

2. Experimental

An intense light beam of frequency ω generates second harmonic, SH, in a nonlinear crystal NLC.

A dichroic mirror, M, reflects the second harmonic at 2ω , and a part of the fundamental, F, in the opposite direction. A phase-adjusting glass plate, P, provides the necessary phase relation between the two reflected light waves at ω and 2ω . Figure 1 illustrates the basic idea of the nonlinear mirror.

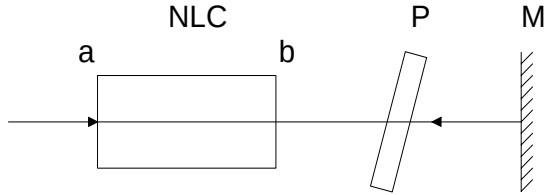


Fig. 1. The nonlinear mirror: NCL- nonlinear crystal for SGH; P-phase-adjusting glass plate; M-dichroic mirror; a, b-left and right-hand boundaries of the NLC.

In the second pass through the nonlinear crystal, partial reconversion of the second harmonic into fundamental takes place. The higher the intensity of the incident beam the higher is the conversion into second harmonic and higher is the amplification of the reflected fundamental due to the presence of the second harmonic wave. Hence one should expect that the resulting reflectivity increases with the increase of the intensity of the incident beam. After the first pass through the nonlinear crystal the phase shift between F and SH is $\pi/2$. A phase change of $-\pi$ may be obtained by tilting the glass plate, using the dispersion in glass, or by changing the distance between the nonlinear crystal and the dichroic mirror, using the dispersion in air [9].

3. Principle of operation

The nonlinear behavior of the mirror is expected to be more pronounced for high conversion into the second harmonic (SH), the depletion of the fundamental wave (F) is considerable and thus cannot be neglected. We denote the real amplitudes of the fundamental waves and the second harmonic with Q_1 and Q_2 , and introduce a new variable:

$$\delta = C \cdot \sqrt{Q_1^2 + Q_2^2} \cdot z. \quad (1)$$

Here, z is the distance traveled by the waves in the nonlinear crystal; C is a constant, which includes the second-order nonlinear susceptibility, and the quantity in the brackets is the total power flow. Then the normalized amplitudes for the fundamental wave (F), u , and second harmonic (SH), v are:

$$u = \frac{Q_1}{\sqrt{Q_1^2 + Q_2^2}}, \quad (2)$$

$$v = \frac{Q_2}{\sqrt{Q_1^2 + Q_2^2}}$$

and obey the equations:

$$\begin{cases} \frac{du}{d\delta} = -\sin \Theta \cdot y(x) \cdot z(x) \\ \frac{dv}{d\delta} = \sin \Theta \cdot y^2(x) \end{cases} \quad (3)$$

where $\Theta = 2\Phi_1 - \Phi_2$ is the phase difference between the two light waves with initial phases and for F and SH. Power conservation requires that $u^2 + v^2 = 1$. The solution of these equations is obtained in Scilab; it is defined the function which solves numerically the system of equations (3) using the following code.

```
Function y=f(t,x,a)
y(1)=-a*x(1). *x(2);
y(2)=a*x(1).^2
endfunction
a=1; vx=[0,0.2,0.4,0.6,0.8,1];
n=length(vx); mat1=ode([1;0],0,vx,f);
```

The numerical solutions obtains for the F and SH are presented in Table 1.

Table 1. The numerical solutions of the fundamental F, and of the second harmonic, SH as a function of the coordinate δ .

Sample	1	2	3	4	5	6	7
δ	0	0.2	0.4	0.6	0.8	1	1.2
F	1	0.980	0.925	0.844	0.748	0.648	0.552
SH	0	0.197	0.379	0.537	0.664	0.761	0.827
δ – a coordinate F – the fundamental waves SH – the second harmonic waves							

The analysis of nonlinear mirror is simplified by the fact that one may use relative intensities to evaluate the nonlinear reflection coefficient. A useful parameter is the power conversion efficiency into SH, which we denote by η . The normalized amplitudes of the SH and F after the first pass through the nonlinear crystal and the coordinate δ are:

$$v = \sqrt{\eta}, \quad u = \sqrt{1 - \eta}, \quad \delta = \text{arctgh} \sqrt{\eta}. \quad (4)$$

If the power reflection coefficients of the mirror M for F and SH are R_ω and $R_{2\omega}$, respectively, the amplitudes of the reflected light waves at ω and 2ω are:

$$Q_1' = u\sqrt{R_\omega}, \quad Q_2' = v\sqrt{R_{2\omega}}. \quad (5)$$

The total power flux, which enters the NCL after reflection by the mirror, is $Q_1 + Q_2$ and the new coordinate δ , corresponding to this power flux is:

$$\delta' = C\sqrt{Q_1'^2 + Q_2'^2} \cdot z = \delta\sqrt{Q_1'^2 + Q_2'^2}. \quad (6)$$

One can find the new value of the normalized SH amplitude at the exit plane of the nonlinear crystal in the backward direction:

$$v'' = \tanh \left(\delta' - \operatorname{arctgh} \frac{Q_2'}{\sqrt{Q_1'^2 + Q_2'^2}} \right). \quad (7)$$

Then the normalized intensity of the fundamental wave, emerging from the nonlinear mirror is:

$$u'' = 1 - v'' \quad (8)$$

The intensity of the amplified fundamental represents the nonlinear reflection coefficient R_{NL} , because the intensity of the incident fundamental is chosen to be equal to 1:

$$R_{NL} = u''^2 (Q_1'^2 + Q_2'^2) \quad (9)$$

4. Results and discussion

The analysis of nonlinear mirror is simplified by the fact that one may use relative intensities to evaluate the nonlinear reflection coefficient. An illustration of the variation of F and SH light wave powers is presented in Fig. 2. The experimental dates are presented in the Table 2.

Table 2. The experimental dates of the fundamental F, and of the second harmonic SH as a function of the coordinate δ .

Sample	1	2	3	4
δ	0	0.4	0.8	1.2
F	1	0.917	0.738	0.550
SH	0	0.329	0.567	0.812
δ – a coordinate				
F – the fundamental waves				
SH – the second harmonic waves				

The conversion efficiency into SH is 70%, the reflection coefficient of the mirror M is 0.99 for SH and 0.1 for F.

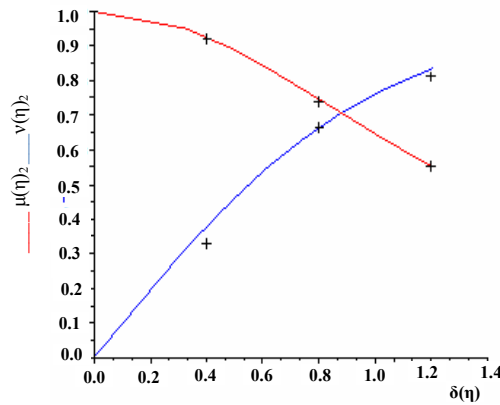


Fig. 2. The variation of wave intensities, of the fundamental F, and of the second harmonic SH as a function of the coordinate δ —comparisons between numerical solutions (continuous line) and measured values (+ - dots).

Calculations were carried out using the last expression for the nonlinear reflection coefficient. Fig. 3 illustrates the ratio R_{NL}/R_ω as a function of the conversion efficiency. The value R_ω includes the reflection coefficient for F and all additional losses, which may arise.

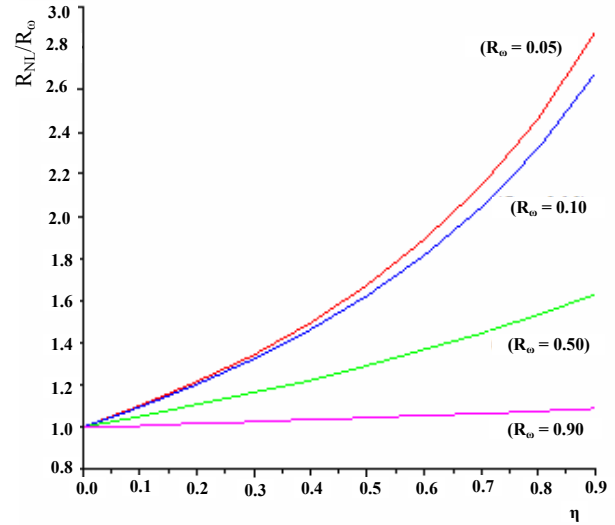


Fig. 3. The normalized nonlinear reflection coefficient R_{NL}/R_ω as a function of the conversion efficiency for several values of the reflection coefficient R_ω .

The four different values for R_ω demonstrate clearly, that the nonlinear behaviour is more pronounced for low reflection coefficients. The higher of the reflectivity R_ω , the lower is the relative change of the back-reflected and amplified fundamental. An illustration of this feature is given in Fig. 4, where the ratio R_{NL}/R_ω is plotted as a function of the linear reflection coefficient R_ω for four values of the conversion efficiency.

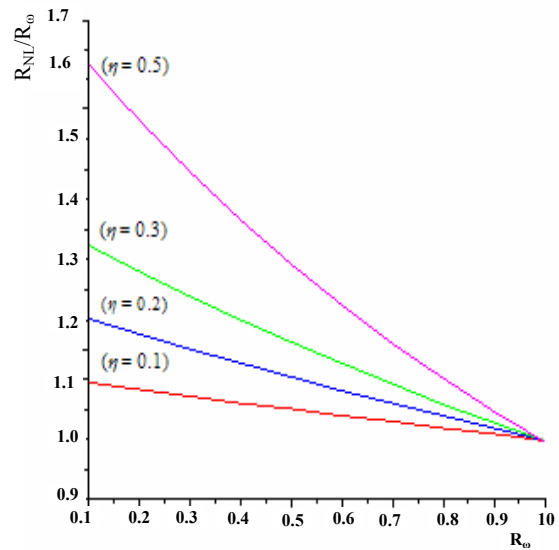


Fig. 4. The normalized nonlinear reflection coefficient R_{NL}/R_ω as a function of the conversion efficiency for several values of the reflection coefficient R_ω .

5. Conclusions

Radioactive and climatologic effects of aerosol (absorbing aerosol) are fully associated with its soot component that have to form the basis of model computations. The particles suspended in the atmospheric air, are carried out using the laser. In this paper we present an analysis of a nonlinear mirror, which uses second harmonic generation as well as reverse process, i.e. amplification of the fundamental radiation in presence of the generated second harmonic radiation using Scilab program. Other reversible nonlinear optical processes may be used as well, widening the area of applications of this device. In comparison with the saturable absorbers, the new nonlinear mirror is superior with respect to high durability, simplicity, fast time response and spectral ranges of application.

Acknowledgements

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