ISSN 0735-2727, Radioelectronics and Communications Systems, 2015, Vol. 58, No. 9, pp. 411–416. © Allerton Press, Inc., 2015.
Original Russian Text © A. Zamudio-Lara, S.V. Koshevaya, V.V. Grimalsky, F. Yanez-Cortes, 2015, published in Izv. Vyssh. Uchebn. Zaved., Radioelektron., 2015, Vol. 58, No. 9, pp. 33–40.

Frequency Multiplication of Terahertz Radiation in the Crystals of Strontium Titanate Paraelectric

A. Zamudio-Lara, S. V. Koshevaya*, V. V. Grimalsky, and F. Yanez-Cortes
Universidad Autónoma del Estado de Morelos, Cuernavaca, Morelos, Mexico
**e-mail:* svetlana@uaem.mx
Received in final form April 27, 2015

Abstract—In this article we have investigated frequency multiplication in the crystals of strontium titanate paraelectric at a temperature of 77 K. Frequency dispersion affects the process of harmonics generation. It has been shown that the efficiency of higher harmonics generation is high and it is equal to 30%. One can perform the selective extraction of certain harmonic by means of an optimal choice of the crystal length.

DOI: 10.3103/S0735272715090034

1. INTRODUCTION

In recent years there is an intensive development of terahertz (THz) range 0.1–30 THz, which has found its application in imaging, spectroscopy, broadband communications, radio astronomy and microwave imaging [1–3]. For the generation of THz radiation one utilizes sources of the optical type (lasers, optoelectronic antennas) and of the microwave type (backward-wave tubes, gyrotrons, diode generators) [1, 2]. However, the efficiency of these sources is low, and usually it is less than several percents.

The frequency multiplication, which utilizes Schottky diodes and diodes based on heterostructures as nonlinear frequency multipliers, is quite promising in the THz frequency range. In recent years a significant progress has been achieved in this area [3–5], but the diode multipliers possess low electrical strength and require the application of resonant waveguide structures.

Since 1960s for frequency multiplication of the microwave radiation one utilizes the nonlinear dielectrics, namely ferroelectrics in the nonpolar phase, the so-called paraelectrics of strontium titanate $SrTiO_3$, kalium tantalate $KTaO_3$ and ceramics based on them [6–15]. Paraelectrics are characterized by high electrodynamic nonlinearity and low losses at low temperatures [6–10]. The high efficiency of nonlinear frequency up conversion in the microwave range has been demonstrated [11–15].

In recent years the utilization of paraelectrics and composite materials based on ferroelectrics in the THz range is being investigated [9, 16–18]. $SrTiO_3$ crystal in the lower part of THz frequency range below the unstiffened mode (~1 THz) has high nonlinearity and low losses at moderately low temperatures 50–90 K [6–8], but in contrast to the microwave range the frequency dispersion of permittivity should be taken into account [9, 17]. The lowest optical (electrically active) mode of crystal lattice vibrations of paraelectric is called the unstiffened mode, because its frequency is significantly lower than the frequencies of other optical lattice vibrations [6–8]. For $SrTiO_3$ crystal the frequency of the unstiffened mode decreases with temperature [6]. At the temperature of paraelectric–ferroelectric transition, for example, in the case of barium titanate $BaTiO_3$, the frequency of the unstiffened mode tends to zero.

In this paper we investigate the generation of higher harmonics of millimeter and THz radiation in crystal strontium titanate paraelectric in the presence of a constant electric bias field, when the dominant nonlinearity is quadratic. We have considered the case of nitrogen cooling level 77 K. The high efficiency of higher harmonics generation has been demonstrated, we have investigated the influence of frequency dispersion and indicated the possibility of selective excitation of a particular harmonic depending on the length of a crystal. There exists an optimum of conversion efficiency versus the electric bias field.

2. THE PROPERTIES OF PARAELECTRICS IN THz RANGE AND BASIC FORMULAS

Let us use the following formula for the linear permittivity of paraelectrics, which is valid in the microwave and THz ranges [6, 9]: