Experimental study of the harmonic generators and detectors, based on superlattices in wide frequency range 600-2200GHz.

D.G.Paveliev, Yu.I.Koschurinov, A.M.Baryshev[1], W.Jellema[2], V.M.Ustinov[3], A.E.Zhukov[3].

Radiophysics Department, Nizhny Novgorod State University, Russia,
[1]Kapteyn Institute, Groningen University, Netherland,
[2]SRON-Groningen, Netherland
[3]Ioffe Physico-Technical Institute, St.Petersburg, Russia.

We present an experimental study of the harmonic generators based on superlattices at room temperature in wide frequency rang 600-2200GHz. The non-biased superlattice diodes was driven by an electric field with of 120-140GHz and 190-220 GHz. The frequency synthesizers (20GHz) with frequency multiplier chains and MIMIC [1] power amplifiers was used for pump. We measured the power spectrum of output signal using Fourier Transform Spectrometer with cooled Si-bolometer. We observed intensive enough 3th (apr. 50-100mkW), 5th (apr.10-20mkW),7th (apr.1-2mkW),9th(apr. less 0.1mkW) and 11th(apr.1-20 pW) harmonics.

We present also an experimental study the detector, based on superlattices at room temperature in wide frequency rang 600-2200GHz. For this we used the second generator of harmonics with bias such as harmonic-mixer with the same frequency synthesizers (20GHz) with frequency multiplier chains and MIMIC [1] power amplifiers for heterodyne pump. For investigation we used the first harmonic generator such as the source of the THz signal.

In a result in a report we demonstrate that a transmission line for frequency range 600-2200GHz can be achieved at room temperature by making use of superlattice devices for both generation and detection of the radiation.

Experimental study of the harmonic generators

The central element of the harmonic generator was a superlattice electron device (SLED). The SLED (Fig. 1a), prepared by a microstructuring technique, had a quasi planar design with an active small-area superlattice mesa in series with a large-area mesa serving as ohmic contact [2].

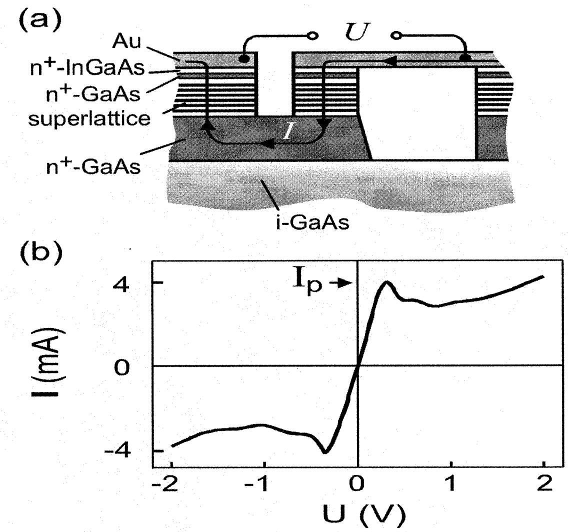

Fig. 1: (a) Sketch of the SLED based on the GaAs/AlAs superlattice; (b) SLED current-voltage characteristic at 300 K

High-frequency currents flew through a gold pad, the active element, an n^+ GaAs layer and the large-area mesa to the second contact pad or in the reverse direction.

The superlattice (length 112 nm) had 18 periods, each period (length 6.22 nm) with 18 monolayers GaAs and 4 monolayers AlAs and was homogeneously doped with silicon (2×10^{18} cm^3). The miniband width (25 meV) was sufficient to lead to miniband rather than hopping transport. By molecular beam epitaxy, we had grown, on an intrinsic-GaAs substrate, an n^+ GaAs layer (thickness 1.5 μm; doping 6×10^{18} cm^{-3}), GaAs/AlAs gradual layer (thickness 32 nm), then the superlattice, again a gradual layer and n^+ GaAs and an n^+ InGaAs gradual layer (25 nm) and finally an n^+ InGaAs layer (20 nm, doping 10^{19} cm^{-3}) serving as ohmic contact. The gradual layers delivered smooth transitions with respect to layer thicknesses and doping, respectively. The same type of superlattice has been used for frequency multiplication [3].

Current-voltage characteristic of the SLED subject to a static voltage is presented in Fig. 1b. The current increases almost linearly for a voltage smaller than the critical voltage (U_c), reaches its maximum value (I_p) at the critical voltage and then decreases. Kinks in the current-voltage characteristic can be attributed to the formation of the electric field domain within the superlattice region.

Output spectrum of the harmonic generator was measured using Fourier Transform Spectrometer (FTS). The non-biased superlattice diodes was driven by an electric field with of 120-140GHz and 190-220 GHz. The frequency synthesizers (20GHz) with frequency multiplier chains and MIMIC [1] power amplifiers was used for pump. Absolute amplitude of the response was not calibrated. Results of the tests at 300 K are presented in Fig. 2a,b,c.

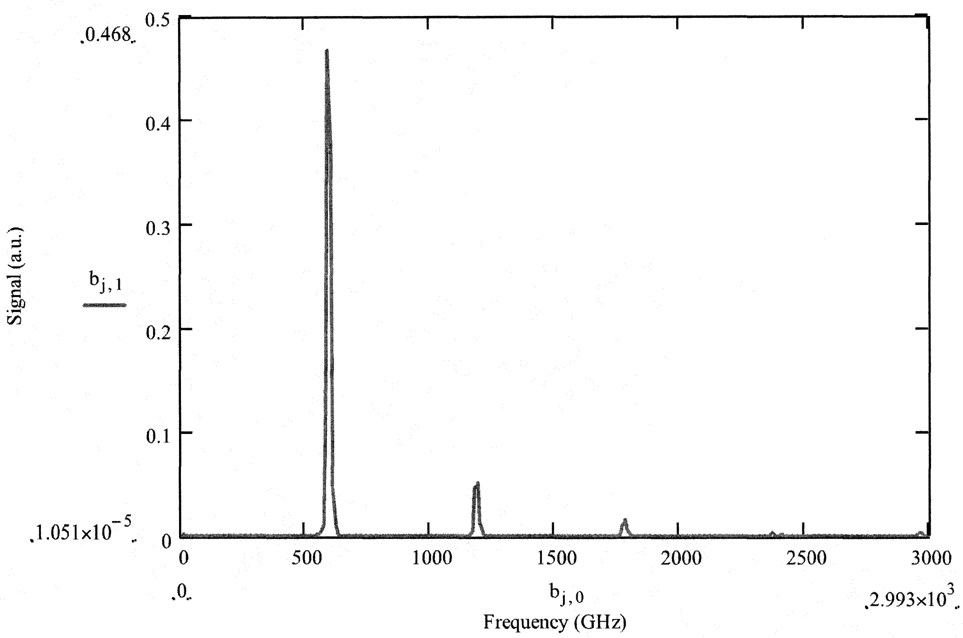

Fig2a.The output signal with input frequency 197.4GHz. Observed intensitive enough 3th (apr.50-100mkW) harmonic.Befor bolometer was used 12dB attenuation.

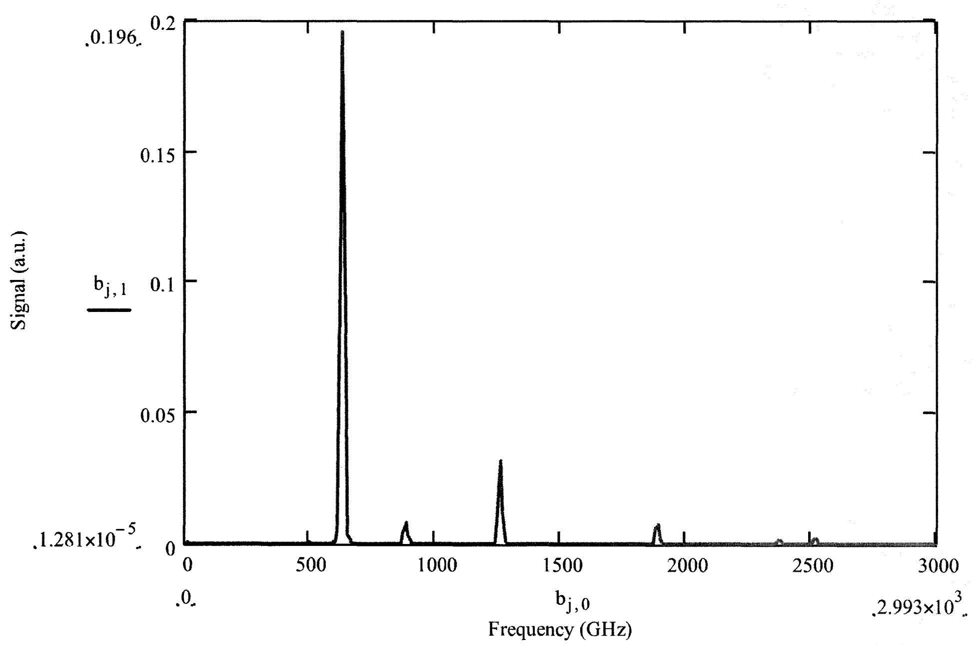

Fig2b. The output signal with input frequency 124 GHz. Observed the intensive enough 5th (apr.10-20mkW)and 7th(apr.1-2mkW) harmonics. Befor bolometer was used 12dB attenuation.

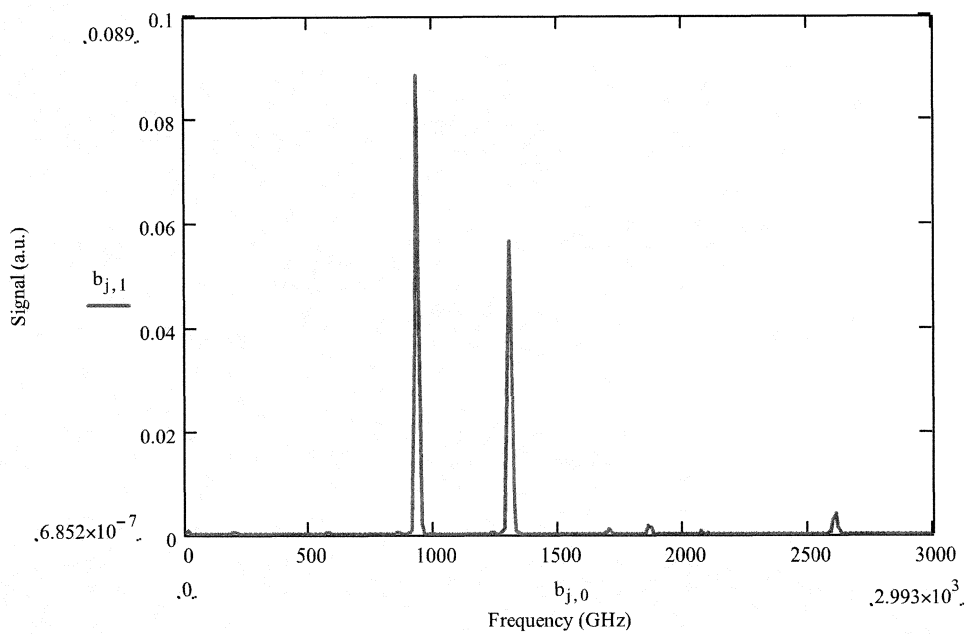

Fig.2c. The output signal with input frequency 187.2 GHz. Observed the intensive enough 5th,7th (apr.1-2mkW) harmonics.The 9th,11th harmonics was visible(apr.1-20pW).

Experimental study of the harmonic mixers

The principle of the semiconductor-superlattice frequency harmonic generators and mixers is based on the nonlinearity of the motion of miniband electrons. The nonlinearity manifests itself in the current-voltage (I-V) characteristic of a superlattice (Fig. 3a). Above a critical voltage V_c (and also below $-V_c$) a current jump appears, which is due to the formation of dipole domains. Under the action of the LO voltage, the superlattice is periodically brought into states of domain formation and annihilation (Fig. 3b), joint with current components at frequencies which are multiples of the LO frequency.

An RF field with a frequency near one of the harmonics of the LO frequency influences the domain dynamics and gives rise to a current, joint with an field at an intermediate frequency (IF); we performed our experiment with an LO frequency near 200 GHz and detected radiation of a frequency more 300 GHz, produced by harmonic generator, based on superlattice, by measuring the IF signal 0.5-5 GHz, i.e., we operated the superlattice mixer in $(2\text{ -}11)^{th}$ mixing order.

Fig. 4. Principle of the superlattice harmonic mixers. (a) Slope of an I-V characteristic of a superlattice with current jumps at the critical voltages V_c and $-V_c$; I_p, peak current. (b) LO voltage (frequency ~ 200 GHz) with an amplitude exceeding the critical voltage V_c and RF voltage due to the RF radiation (frequency more 300 GHz).

The typical IF signal (Fig. 4) showed a sharp peak and a broad background (halfwidth ~ 100 kHz). The noise (level of 10^{-11} W at a resolution bandwidth of 1 kHz) was caused by the frequency mixer.

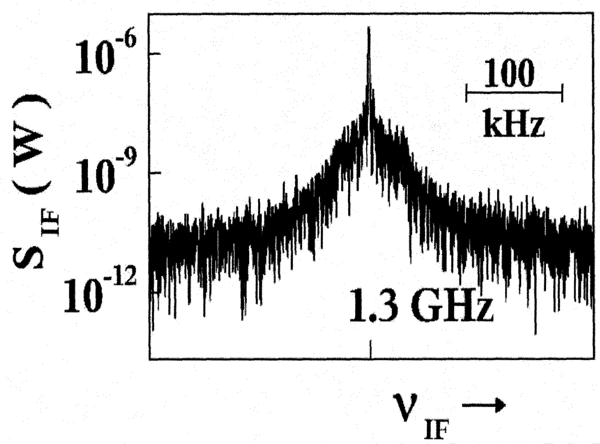

Fig. 4. IF signal at resolution bandwidth of 1 kHz (LO power 2-5 mW, LO frequency 193 GHz, RF Power 100 μW, RF frequency 963.7 GHz).

Reduction of the power of the RF radiation resulted in a corresponding reduction of the signal peak.

Discussion

A superlattice mixer has already been used for stabilisation of a submillimeter flux flow oscillator (frequency range 270 GHz to 440 GHz) [4] and of a backward wave oscillator (700-900 GHz) [5].

The creation and annihilation of a domain can take place within a time which corresponds to a few times the electron relaxation time (~ 10^{-13} s). Accordingly, mixing on the basis of domains in a superlattice should be possible up to a frequency of few THz.

Our experiment also demonstrates that a transmission line for submillimeter radiation can be achieved by making use of the superlattice devices for both generation and detection of the radiation.

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