Modeling of Dynamic Effects in a Laser-Driven Semiconductor Switch of High-Power Microwaves

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***Abstract*— We investigate non-stationary problems of high-power microwaves penetrating into and reflecting from a semiconductor (silicon) plate. The plate is the base of switch activated by laser-driven photoconductivity and changing its properties when heated by the switched microwave power. Analytical criteria for the stationary solutions of the activated (quasi-metallic) and deactivated (dielectric) states of the switch under the conditions of high-power microwave heating and external cooling are found. Results of numerical simulations are also given for the problems of the switch activation by microwave heating initiated by pulsed laser radiation, which increases the carrier density rapidly. Numerical simulations are carried out by means of the finite-difference time-domain method with the unsplit perfectly matched layer absorbing boundary conditions. We demonstrate various types of solutions which depend on the basic parameters of the problem, namely, microwave field intensity, laser pulse energy and semiconductor doping..**

I. Introduction And Background

Semiconductor-based switches of high-power microwave radiation are used to switch high energy microwave beams with limited apertures in high-power electronic devices including particle accelerators, radars, pulsed heaters, etc. The operation principle of such switches is well-known [1]-[3], though all of them are mainly studied in experiments. The present work is intended to develop a simple theoretical model of the switch that includes a quantitative description of the basic effects, such as:

- ohmic heating of the semiconductor plate by the switched microwave radiation,
- saturation of carrier mobility of a semiconductor for high microwave fields close to the breakdown threshold,
- a rapid change in the non-equilibrium carrier density due to the photoconductivity induced by an external laser pulse,
- relaxation of carrier density caused by intrinsic properties of the semiconductor crystal,
- carrier diffusion and heat transfer processes.

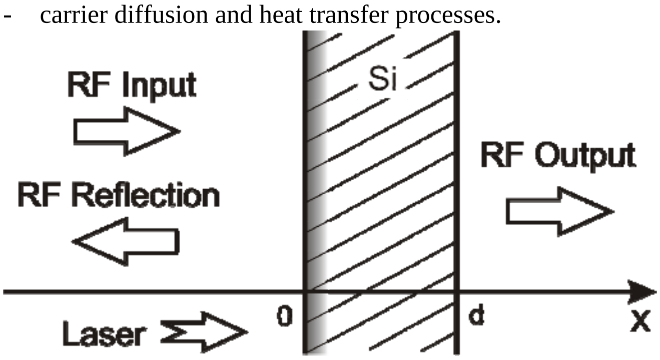

Fig.1. Schematics of the semiconductor switch

A simplified scheme of the switch is shown in Fig.1. A plane input wave (with a wavelength of 1 cm, in this paper) is incident on a semiconductor plate. In standby, the semiconductor is a low-loss dielectric. In this state, the RF input power is transmitted without significant absorption and reflections.

The semiconductor plate may be also exposed to a short laser beam pulse. That allows a rapid (sub-nanosecond) increase in the carrier density in a thin (about several μm) layer close to the boundary (to the left in Fig.1) due to induced photoconductivity. In this case, almost all of the input RF power is reflected (up to 95% and more, [3]). This is the enforced switching.

After the end of the laser pulse, the carrier density starts relaxing to its equilibrium value. After that, the silicon plate returns to its standby state, and the input power is switched off. In addition to the induced photoconductivity, the density can also be increased due to the ohmic heating of the plate with the switched RF power. The later process may result in an avalanche-like temperature growth accompanied by the carrier density increase, with subsequent switching on even without any laser-induced photoconductivity.

II. Results

The utilized numerical simulation method is proven to describe the dynamic effects of the switching based on photoconductivity and microwave heating. The theoretical criteria are given for two stationary states, namely, switched and unswitched. A low-purity silicon plate with rather high initial carrier density can switch even without a laser pulse, just by heating with high microwave power passing through. A laser pulse can either accelerate or decelerate the process of switching. Low-energy laser pulses decrease the switching time due to moderate photoconductivity induction. Laser pulses with high energy lead to almost ideal reflection of the microwave power. This can increase the switching time.

A real experiment is planned for practical models of the switch with high-power switched microwave radiation.

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