NEGATIVE ABSOLUTE ELECTRICAL CONDUCTIVITY OF OPTICALLY
EXCITED RUBY: MICROSCOPIC NATURE OF THE PHENOMENON

S.A. Basun, A.A. Kaplyanskii and S. P. Feofilov

Ioffe Physical Technical Institute
USSR Academy of Sciences
194021 Leningrad, USSR

1. INTRODUCTION

Ruby, Al₂O₃:Cr³⁺, is clearly an insulator, its electrical conductivity becoming finite only under optical excitation. Recently, the unusual photoelectrical properties of ruby have become a subject of considerable interest. A study has been carried out at a low (~ 10 K) temperature on crystals of concentrated ruby of the effect of intense Ar laser irradiation in the region of the broad U and Y absorption bands. A strong uniform electric field $E_s \sim 10^6$ V/cm directed along the trigonal C axis was found to appear gradually and reach saturation in the excited region of the crystal; the field persisted after the pumping was turned off and the sample warmed up to room temperature.

The photoinduced field in ruby was established to have a complex spatial structure consisting of regions (domains) with equal but oppositely directed electric fields ($\pm E_s$). The phenomenological theory connected the formation of photoinduced field domains with the electrical instability of optically excited ruby against small fluctuations of the electric field. This instability comes from the anomalous character of the dependence of photocurrent $j_{\parallel}$ on the electric field parallel to the C axis. It was assumed that the $j_{\parallel}(E)$ relation has an N-shaped feature near zero (see Fig. 1). Namely, at fields $-E_s < E < +E_s$, the absolute electrical conductivity is negative and the photocurrent flows against the field, while in the interval $-E_t < E < +E_t$ the differential conductivity is also negative. The current flow against the field for $|E| < |E_o|$ was phenomenologically explained as due to the current being actually a bulk photovoltaic current which is induced in centrosymmetric ruby crystals by the electric field.

The N-shaped $j_{\parallel}(E)$ dependence was directly observed experimentally in measurements of the I-V characteristic of the stationary photocurrent in ruby, $j_{\parallel}(E_0)$, in the presence of an external field $E_0$ produced in ruby plates ($d = 0.1 + 0.2$ mm thick) by applying a voltage $U$ ($E_0 = U/d$) (see inset in Fig. 1). As seen from Fig. 1, at fields $E_0 < E_s$ the current $j_{\parallel}$ is opposed to the field and reverses sign at $E_s = E_0 (= 475$ kV/cm). The measured $j_{\parallel}$ is essentially a stationary current flowing indefinitely through a homogeneous sample. Thus the measurements of $j_{\parallel}$ fully confirm the main assumption of the phenomenological theory of the formation of induced domains containing strong electric fields in ruby.

It should be pointed out that the N-shaped anomaly in $j//E_0$ resulting in an electrical instability of optically excited ruby occurs within a critically bounded interval of conditions, namely, at chromium concentrations $c>c_C = 0.15\%$, temperatures $T<T_C = 150\text{K}$, and pumping densities $P\geq10\text{KW/cm}^2$. In fields $E_0|C$, the I-V characteristic of ruby always has a shape which is close-to-ohmic (Fig. 1).

Fig. 1. Schematic representation of the N-shaped field dependence of photocurrent, $j//E_0$, for $E|C$ (dashed line) and experimental I-V characteristics of the photocurrent $j$ in external fields $E_0|C$ ($\circ$) and $E_0|C$ ($\ast$), $T = 77\text{K}$. Inset: schematic of measurements; 1 - laser beam (514.5 nm); 2 - transparent electrodes; 3 - electrometric amplifier.

The present paper reports on recent kinetic and spectral measurements of the photocurrent which provide an insight into the microscopic nature of the absolute negative electrical conductivity of optically excited ruby in fields $|C$.

2. Kinetics and Spectrum of Photocurrent: Experimental Data

2.1 Photocurrent Kinetics

The photocurrent kinetics was measured using the scheme of Fig. 1 (see inset). The crystal was excited with rectangular pulses by properly chopping the Ar-laser beam (Fig. 2a). The large pulse duration, with long off intervals, permitted the current to reach saturation. Fig. 2b-d shows the measured time dependence of the photocurrent for three values of the applied external field $E_0|C$ corresponding to the positive ($E_0 > E_S$), zero ($E_0 = E_S$), and negative ($E_0 < E_S$) values of the stationary current $j_{st}$ observed under