



amplitude spectra of reference and sample signals respectively,  $\lambda$  is a wavelength.

Then, monolayer graphene complex conductivity can be calculated by the next equation [3]:

$$\dot{\sigma}_f(\omega) = \frac{[\dot{n}_{\text{sub}}(\omega) + 1]\dot{E}_{\text{sub}}(\omega) - \dot{n}_{\text{sub}}(\omega) - 1}{Z_0 \dot{E}(\omega)}, \quad (4)$$

where  $\dot{n}_{\text{sub}} = n'_{\text{sub}} + in''_{\text{sub}}$  - complex refractive index of bare substrate,  $\dot{E}_{\text{sub}}(\omega)$  and  $\dot{E}(\omega)$  are complex amplitude spectra for bare substrate and sample with graphene respectively,  $Z_0=377$  Om is the impedance of free space.

It is worth noting, the complex permittivity can be obtained from the following equation:

$$\dot{\epsilon}_f(\omega) = 1 + i \frac{\dot{\sigma}_f(\omega)}{\omega \epsilon_0 t_f}, \quad (5)$$

where  $\epsilon_0$  is the dielectric constant,  $t_f$  is a thin (graphene) thickness. So, as seen from the equation (5) if the real part of graphene conductivity is becoming negative, the imaginary part of permittivity is becoming negative too, that means generation process instead absorption.

#### IV. RESULTS

In the Figure 2 the real part of conductivity of monolayer graphene on PET substrate under the influence of optical radiation by various pumping power is shown.

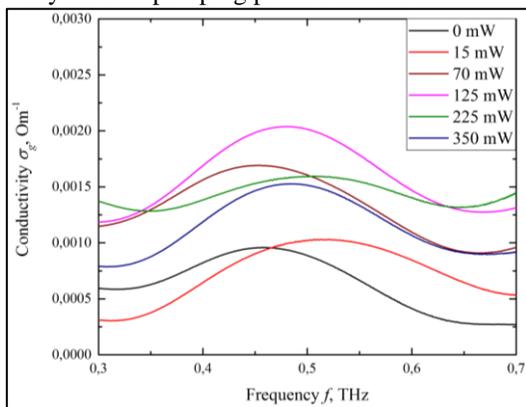


Fig. 2. Experimental spectra of monolayer graphene conductivity on PET substrate.

From Figure 2 it is seen that graphene conductivity is increasing with increasing of optical pumping power. But after 125 mW it directs toward negative values.

In Figure 3 the spectra of conductivity of graphene on quartz substrate were shown. According the paper [4] the substrate permittivity influences on graphene conductivity, so spectra of graphene conductivity on PET differentiate with spectra of graphene conductivity on quartz.

In the high frequency range graphene has negative conductivity without optical pumping. This result repeats four times in different experimental series. The explanation of the effect of negative graphene conductivity without pumping can be found in paper [4].

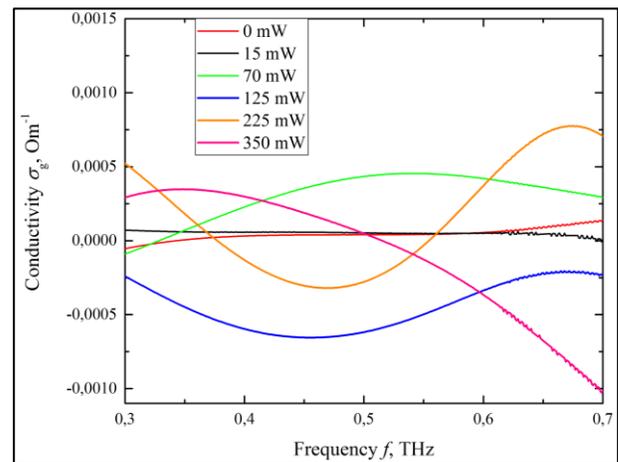


Fig. 3. Experimental spectra of monolayer graphene conductivity on quartz substrate.

As well as in PET case the conductivity of graphene on quartz substrate increases with pumping power increasing, but for 125 mW the conductivity is become negative. By growing the pumping power the conductivity is partially becoming positive, but somewhere is still negative.

#### V. CONCLUSION

It is shown that monolayer graphene on different substrates has diverse dynamics of conductivity value changing. Experimentally negative conductivity of monolayer graphene on quartz substrate was obtained, that means the generation of radiation in these frequency ranges. The negative conductivity on PET substrate was not obtained, but at pumping power more than 350 mW it may be possible.

#### VI. FUTURE PLANS AND ACKNOWLEDGMENT

In near future I plan to carry out experiments with temperature and magnetic field influence on graphene conductivity (currently, it is only at theoretical simulation stage). And due to IEEE MTT-S Undergraduate/Pregraduate Scholarship I can to complete my project. I would like to thank IEEE MTT for the opportunities that are given to students all over the world in their research projects development.

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