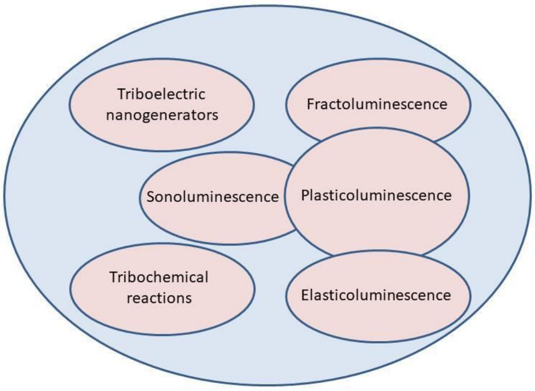
Mechanoluminescent displays and sensors based on nanostructured piezoelectric materials

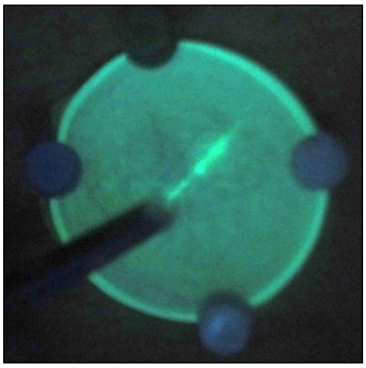
The phenomenon of mechanoluminescence (triboluminescence) is known already for about four centuries. Francis Bacon found it while crumbling sugar, Robert Boyle described it for diamond and since then it was observed for many inorganic and organic compounds. However, due to its relatively weak light emission and stochastic nature only recently it became a subject of intensive research, both basic and applied. Mechanoluminescence is the effect of light emission under mechanical stimuli, such as fracture, friction, impact, bending or twisting, which leads to elastic or inelastic deformation of the material. Therefore, depending on the type of generating deformation, mechanoluminescence can be divided into fracto- , plastico and elastico-luminescence. Recently, there is a lot of interest in this phenomenon, as well as in related effects, such as tribochemical reactions or triboelectric generators. In fact, some of the above mentioned effects occur simultaneously.



Mechanoluminescence (triboluminescence) and related phenomena

During this project we will synthesize and study selected materials, for which the mechanoluminescence is relatively strong. We will study the mechanisms of this phenomenon, which might be different depending on the type of material, its crystallographic structure, presence of crystal defects, dopants etc. From that point of view the materials doped with rare-earth and transition metal ions exhibiting so called persistent luminescence are very important candidates for our mechanoluminescence experiments. Persistent luminescence is related to existence of so called trap levels in the material, which catch the electrons or holes excited by incoming light. The trapped charges can be next slowly released giving rise to long-lasting luminescence, with very long decay times. The energy necessary for detrapping the electrons and holes from the trap levels depends on the energy ("depth") of the trap levels in relation to the conduction and the valence bands. Mechanical stress may provide additional energy which can release the charges from the traps. Such free charges may then recombine leading to mechanoluminescence. Thus mechanoluminescence may be used for easy and immediate detection and visualization of the occurrence of local stress, tensions, etc. An example is presented in the picture below. The photograph shows the bright trace of enhanced emission of green light as the effect of stress generated with a metal stick on the PVDF foil with embedded $Sr_2MgSi_2O_7$: Eu, Dy.

Doped piezoelectric crystals belong to the especially prospective materials for mechanoluminescence applications. However, piezoelectric properties of the crystal do not guarantee that it will exhibit mechanoluminescence. Very recently it was found that stoichiometric $LiNbO_3$:Pr shows exceptionally strong triboluminescence [Dong et al. Adv. Mater. 2017, 29, 1606914;]. Also $LiTaO_3$:Pr was reported as a very efficient piezoluminecent phosphor [Gaojian Qiu et al, Ceramics International, 45 (2019) 8553]. In our project $LiNbO_3$ single crystals with various stoichiometry doped with rare-earth and transition metal ions as well as the related materials, such as $LiTaO_3$,or $KNbO_3$ will be studied in order to obtain the most efficient material with the possibility of color tuning. Also mechatronic properties of another piezoelectric material, i.e. GaN and ZnO in the form of nanowires grown either by hydrothermal method (in case of ZnO) on various substrates such as silicon, glass, and quartz or by molecular beam epitaxy (GaN) will be examined. High pressure studies in the diamond anvil cells of such materials are planned.



Picture of PVDF foil with embedded $Sr_2MgSi_2O_7$: Eu, Dy, manufactured in the Institute for Electronic Materials Technology, exhibiting mechanoluminescence under stress. (photograph of the authors of the proposal)

Mechanoluminescent composites manufactured from materials with strong triboluminescence and various types of polymer and epoxy foils as well as glasses will be prepared and examined. Finally, the demonstrator of mechanoluminescence sensor will be produced which will serve as the test device for developed theory of mechanoluminescence and show the path for future applications of such materials.

The project will be implemented in the Institute of Physics of the Polish Academy of Sciences, Institute for Electronic Materials Technology (both in Warsaw) and in the Institute of Experimental Physics, University of Gdańsk.