Electronic States and Phases Induced by Electric or Optical Impacts.

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IMPACT 2012

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Meeting proposal.

Controlled transformations of electronic states and phases by external impacts is a very rapidly developing new activity in condensed matter physics with attractive applications and already moving scientific boundaries beyond their limits. The two major branches address effects of a very strong electric field and a supercritical optical pumping, or their combination. Being as young as from 2000's, the studies demonstrated an explosive development during last two years. The plenary presentations are selected for the latest biggest meeting like the forthcoming APS March meeting and the M2S in the USA. Also a number of smaller focused meetings take place. Still, even within each of the two major branches, there is a lack of interactions, e.g. among studies focused upon cuprates and oxides and those upon organic conductors. But particularly noticeable is a lack of acquaintance and cross fertilization between the branches of the electric and optical impacts. There is an urgent need for a synergetic conference, which may give rise to sequential events in the future. We are planning to organize such a meeting as a five days workshop in September 2012 in France expecting about 100 participants, including students. The event will be based at the University Paris Sud at Orsay close to Paris. Together with nearby institutions like the Saclay center of the CEA, Ec. Polytechnique, synchrotron SOLEIL, the Optical Valley institutes, and the center for photonics and nano-science, this area accumulates much of expertise and already running activity related to our project. We have already inquired with many of major players of that science over the world, and the reaction was typically very positive. The financial support has been already given by the ICAM which accepted the project as a best of the year; and some local funds are being raised.

CONTEXT, POSITION AND OBJECTIVES

Recent years witness an emergence and a very fast development of a new activity in condensed matter physics. The goal is a controlled transformation of electronic states or even of whole phases by external impacts. There are two main directions: the electrostatic effects of very strong electric fields and the supercritical optical pumping; the latest trend is to employ them in combination. These efforts originated a complex broad science which includes the surface physics at scales down to nanometer (in electrostatics), the femto-second time scale of the nonlinear optics, the arts of nano-fabrications by the molecular beam epitaxy (MBE) and by the focused ion beams (FIB); complex materials from cuprates, conducting oxides and now pnictides, to organic conductors and conjugated polymers. The geography of experimental researches embraces major advanced centers, particularly:

France - Orsay pole: Univ. Paris-Sud, synchrotron SOLEIL, Ec. Polytechnique, LPN - Lab. of Photonics and Nano-Science; Grenoble – Inst. Neel at the Polygone Sci., Toulouse – LNCMI (Nat. Lab. of High Magnetic Fields);

Canada	McGill Univ.;
GB	Cambridge and Oxford;
Germany	Univ. of Augsburg, Berlin, Duisburg-Essen, Hamburg, Kiel, and Konstanz, Max Plank Inst. in Stuttgart, and more;

Russia Inst. Radio Engineering & Electronics – IREE;

Slovenia Univ. of Ljubljana;

Switzerland Univ. of Geneva, EPFL in Lausanne;

USA BNL, MIT, Univ. of California, Columbia, Chicago, Maryland, Minnesota, and Stanford;

Japan Univ. of Hokkaido, Tohoku, Tokyo (Applied Physics and Centre for Photonics), Tokyo University of Sci, AIST in Tsukuba, RIKEN in Tokyo, Inst. for Molecular Science IMS at Okazaki.

Our proposal is to realize common grounds and general problems of several directions which today develop very fast but almost no mutual interactions, by only barely overlapping scientific communities. The meeting program will incorporate studies of responses of diverse cooperative electronic states to external impacts.

First group includes already related directions from the decade "old" purely optical femto-second setups to the later time-resolved techniques of the photoemission spectroscopy and of just coming time-sliced diffraction attainable at X-ray laser sources. The theoretical universality suggests to bring experience of sister many-body systems – ensembles of polaritons and excitons.

Second group includes static transformation by highest available electric fields which is a direction of 2000's with an astonishing success in last two years. It is also fruitful to recognize a similarity of lower field phenomena in mesa nano-junctions, fabricated and studied since several years; here we face a combination of static and transient transformations; also there are challenging experiments in very high magnetic fields.

Systems of major interest possess a symmetry broken ground state – from crystallization of electrons (charge order) or e-h pairs (charge/spin density waves) to superconductivity. Hence, any realistic impact creates inhomogeneous states and starts an evolution of topological defects – domain walls, vortices, dislocation lines, down to truly microscopic solitons. That brings a unifying complex of theoretical problems aimed describing many observable effects from macro to micro scales. First principle and model calculations, for both the electrostatic and optical impacts, also start to flourish following the experimental demands.

While principles and methods are universal, differences in implementations play a role. The program shall address several material realizations of symmetrically well defined states: from cuprates, oxides and pnictides to organic conductors. A comparison will be provided among superconductivity, charge density waves, charge ordering, magnetic phases, and Mott insulators.

At present, the described field in general is of a fundamental character which is already very important as moving scientific boundaries beyond their limits (very short times, highest fields) and meeting a popular interest in "emerging phenomena". The same time, the idea of switching between electronic phases, particularly obtaining the superconductivity (even at surface or in short leaving forms) on top of a pristine insulating state targets the applied science including principally new devices.

HISTORY AND STATE OF THE ART

Here we shall characterize the state of the art separately for the two major axes.

I. Field-effect transformations of electronic phases. Junctions and restrained geometries. Expectations for semi-super-conducting electronics and optoelectronics.

The line of the field-effect transformations joins a recent trend in physics of strongly correlated electronic systems to treat, and attempting to exploit, them as a kind of “unconventional semiconductors in unconventional conditions ” [0]. With oxides of transition metals as a first choice application [1,2], the field was recently baptized “oxitronics”. But the very first attempts have been made for cuprates from the family of high-Tc superconductors (J.M. Triscone at Geneva U.), and now under studies there are pnictides, halcogenides of transition metals and organic conductors – with emphasizes upon charge density waves and charge ordering.

The theory line is traced back to suggestions of using the optical injection of solitons, polarons, bipolarons [3], and for the superconductivity induced by the electrostatic doping – FET (field effect transistor) [4,5]. Next proposal [6] was made in response to discovery of n-doped superconducting cuprates, which opened in principle a possibility to create an all-superconducting p-n junction. Experiments (J.Paglione, R.L.Greene, et al at the U. of Maryland) addressed this possibility in cuprates and pnictides.

The experimental success is coming on several lines: the ferroelectrically enhanced field effect in high-Tc superconductors [7,8] (J.M.Triscone group at Geneva U.); optically induced metallization in oxides of transition metals and later in organic materials [9-11] (groups by: K.Miyano and H.Okamoto at Tokyo U., S.Iwai at Tohoku U., H.Cailleau at Renne U.), photo-voltaic combination [12,13] (Z.Hiroi group at ISSP, Tokyo U.), nano-scale FET [14,15] (I.H.Inoue at AIST, Tsukuba), the superconductivity

induced by interlayer charge transfer and also affected by optics [16,17] (I.Bozovic group at BNL) and by ionic field effect [18] (I.Iwasa at Tohoku-Tokyo U. , BNL group, R.Friend group at Cambridge UK), electrostatic doping in thin films (A.M.Goldman group at Minnesota U.).

A way towards applications has been shown recently [19] by observation of an anomalous luminescence from p-n junctions of conventional semiconductors in proximity to superconductors, and the first theory followed [20] (groups by H.Takayanagi at Tokyo U. of Sci. and by I.Suemune at Hokkaido University).

FIB fabricated nanojunctions of charge density waves [21] (Y.Latyshev in Moscow and P.Monceau in Grenoble) allowed to achieve a reconstruction of the electronic cooperative state in moderate electric fields as it was modeled recently [22], adding also the high magnetic field perspective.

II. Optical impacts and nonequilibrium coherent dynamics at femto-second scales. Time-sliced ARPES and X-ray diffraction.

The line of optically induced transformations is based on successes in nonlinear optics with femto-second resolution and in new time-sliced X-ray probes - ARPES and diffraction. The field of fast optically induced processes is broad, and we shall concentrate on the subset of activity related to transformations of electronic phases and to dynamics of cooperative states. Certainly, the whole picture will be summarized at our meeting with more attention to emerging techniques.

The line with optical pump-and-probe includes, among others, activities in Hamburg and Oxford - A.Cavalleri [23], Kiel - M.Bauer [24], Konstanz - J.Demsar, Sendai - S.Iwai, Tokyo - H.Okamoto. A further triple-time method (Ljubljana - D.Mihailovic, with Orsay on theory) allowed to observe a rich picture including coherent undulations of the order parameter followed by a dynamical phase transition and collapses of domain structure [25].

The line of combined experiments exploits the optical pumping followed by other probes such as time-resolved versions of ARPES (angle resolved photoemission spectroscopy) and of X-ray diffraction, accessible at most modern X-ray sources. These innovative leading edge methods are developed in a number of places: L.Perfetti at Ecole Polytechnique [26], M.Marsi and V.Brouet at LPS of Univ. Paris Sud, M.Wolf at Free U. of Berlin, M.Sutton at McGill U., Z.X.Shen group at Stanford U. [27], Nuh Gedik at MIT, the initiative on the time-sliced X-ray diffraction is planned in Konstanz, at SOLEIL near Orsay, etc.

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