Opto-Electronics using Strongly Correlated Electronic System of Perovskite-type Transition-Metal Oxides

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The transition-metal oxides of perovskite-type show metal-insulator transition and high-temperature superconductors depending upon a degree of doping. The overlap-integral between the transition-metal 3d-orbital and the oxygen $2p_\sigma$-orbital is so large reflecting the perovskite structure that the oscillator strength of the charge-transfer excitation becomes also large and this excitation can propagate in the crystal. Furthermore n-type and p-type superconductors can be made of these crystals and photo-excited electrons and holes can also propagate both in the intrinsic and doped crystals.

First, making the best use of large oscillator strength in the visible region, we are planning to develop new laser materials with variable wavelength in the visible region. For example, oxygen-deficient $YAlO_3$ and $LaAlO_3$ single crystals show strong emission in blue and green region under ultraviolet excitation. We have a plenty of combinations A and B metals from ABO_3 perovskite crystals and much freedom of reduction as well as doping degree and doping elements. Therefore we are planning to grow the pure as well as doped ABO_3 crystals. We will optimize the combination of A, B and doped ions for the new laser materials by studying the luminescence spectrum, its dynamics as well as the gain spectrum.

Second, using the advantage of large mobilities of photo-excited electrons and holes in these porovskite crystals, we make the light emitting diode (LED) and laser diode (LD). The optical excitation in visible region and the electron and hole band are made mainly of B^{4+} and O^{2-} orbitals so that we can make the n- and p-type crystals by replacing A^{2+} metal with C^{+} and D^{3+} metals without disturbing the relevant orbitals so much, i.e., by the modulation doping. By choosing the best combination of A,B,C and D metals, we will be able to make the LD and LED in the visible region. This will open the new field of engineering that is called "Periodic Table Engineering".

Third, finally we will replace the n-type and p-type electrodes by the n-type and p-type superconductors, e.g., $Nd_{2-x}Ce_xCuO_4$ and $La_{2-x}Sr_xCuO_4$, respectively. When thin film of insulating antiferromagnet (AF) is sandwiched by these electrons, the electron and hole Cooper pairs can penetrate the insulating AF film by the promixity effect. We will be able to make also the quadrupole structures of two facing n-type superconductors and p-type ones with the AF insulator at the central part. Then we expect electronic Cooper pairs and hole ones to penetrate more deeply into the central AF insulator. These electron- and hole-Cooper pairs overlap spacially so that two photons are emitted into the front and rear directions of the waveguide made from the AF insulator. Both the electron- and hole-Cooper pairs are composing the electronic coherent states. As a result, both Cooper pairs within the coherent range induce the macroscopic transition dipole moment, and two short coherent light pulses are produced into the opposite directions of the waveguide by the superradiant process to satisfy the energy and momentum conservation laws simultaneously.

The peak height is proportional to the square of the number of the involving Cooper pairs N^2 and the pulse width is inversely proportional to N. This number N depends on the injected current as well as the penetration depth of Cooper pairs. This pair of the pulses have a few novel properties : (1) the photon numbers and the phase profiles of these twin light pulses are equal to each other so that they can coherently interfere, (2) once we can observe the photon number of one of these pulses, we can know also the photon number of the other light pulse, and (3) once we trigger the superradiance by the weak regular light pulse series, we will be able to make the regular array of twin light pulses with the equal photon number. This photon number can be well controlled by changing the injection current as well as the waveguide structure.

The use of high T_c superconductors as electrodes has such an advantage as high temperature operation but has a disadvantage that the coherent length is short. In this sense, we are also planning to use conventional superconductors which have much longer coherence length as the electrodes. Then we may expect the deeper penetration depth and the larger number Cooper pairs to be involved in the superradiant emission.

These realization of (1) the frequency variable laser materials in the visible region, (2) the LED and LD which are made of these laser materials, and (3) the superradiant generation of coherent pulse pairs from the electron- and hole-Cooper pairs, will open a new paradigm of opto-electronics.