Nanoquakes at Work: A Quantum Conveyor Belt for Photons

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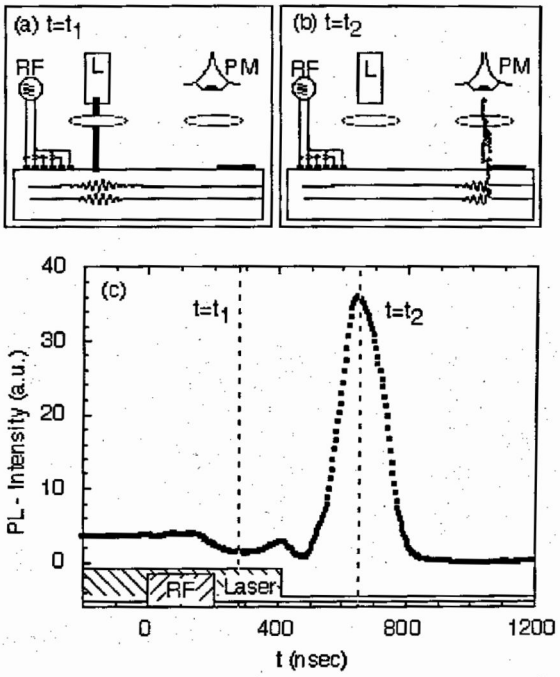
The combination of surface acoustic waves (SAWs) and the superior optical properties of band gap engineered semiconductor layer systems yields a completely new and promising approach toward another generation of optoelectronic devices.[1]

Representing a nanoscale analog to earthquakes, SAWs are modes of elastic energy that can propagate on the surface of a crystal at the speed of sound. If the solid is piezoelectric, which most modern optoelectronic material combinations are, these waves are accompanied by strong electric fields and potentials.[2] Those fields can be exploited to alter the optical properties of a semiconductor sample in a widely tunable fashion.[3] On piezoelectric ceramics, these waves have become invaluable for high frequency signal processing over the last decade or so and the related technologies are very advanced.[4]

In direct gap semiconductors, incident light is efficiently converted into loosely bound electron hole pairs (excitons), which usually live for mere nanoseconds before recombining in a flash of light with a characteristic energy distribution (photoluminescence/PL).

The device reported here makes use of the fact that the strong lateral piezoelectric fields of an SAW can break those excitons apart before recombining.[3] The remaining fragments (free electrons and holes) are then collected into deep energetic minima, being imposed by the SAW on the natural energy levels in the conduction and valence band, respectively. These potential minima for both types of photogenerated charges are laterally displaced by one half acoustic wavelength, about one micron in the present case. Once separated, the electrons and holes are too far apart from each other to recombine (see Fig. 1a). They remain



Wixforth Figure 1. Transport of photogenerated ambipolar charges by a SAW. At t = 0, a 200 nsec long RF pulse at f_{SAW} = 840 MHz applied to IDT_1 generates a SAW packet with an acoustic power of P_1 = 13.5 dBm. At t = t_1 (a) the potential extrema of the SAW are filled with photogenerated electron-hole pairs which are transported with sound velocity to a semitransparent metallization at the other end of the sample. Here the deliberate screening of the piezoelectric potential modulation lifts the spatial separation of the carriers and induces radiative recombination and t = t_2 (b). In (c) the detected light intensity as a function of time is shown. The duration of the RF pulse and the laser pulse are indicated in the lower part of (c).

ence 1 is to simply metalize some part of the surface of the semiconductor quantum well sample. The thin metal layer screens out the lateral electric fields, trapping the charges while traveling across the sample. As on a beach, the potential waves level out, electrons and holes find each other again and the PL leaves the sample at the desired location[5] (see Fig. 1b and 1c). Another way is to use a second, counter propagating SAW to cancel out the effect of the first. Here, by simply adjusting the time delay between both waves, the location and time of the PL pulse can be chosen at will.

Other sample designs are presently being investigated. One promising approach is to steer an optical signal stored in a SAW to form a tiny switchboard for light with inputs and outputs at different locations of the semiconductor surface. Other attempts aim toward the combination of SAW and semiconductor laser structures. So far, only the beginning of a completely new field of research is marked, many other fascinating results are waiting to be explored.

References

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5. A short description of the process, including graphics, can be found at www.aip.org/physnews/graphics/condensed/1997/conveyor/.