THz pulse boosts electron density in GaAs 1000-fold

Kyoto University findings could lead to ultra-high-speed transistors and high-efficiency solar cells.

Researchers at Kyoto University have reported what they claim is a breakthrough with broad implications for semiconductor-based devices ('Extraordinary carrier multiplication gated by a picosecond electric field pulse' by H. Hirori et al, Nature Communications, 20 December issue; doi: 10.1038/ncomms1598). The findings could lead to the development of ultra-high-speed transistors and high-efficiency photovoltaic cells, it is reckoned.

Working with standard GaAs, the team observed that exposing the sample to a terahertz (1000GHz)-range electric field pulse caused an avalanche of electron–hole pairs (excitons) to burst forth. This single-cycle pulse, lasting just a picosecond (10^{-12}s), resulted in a 1000-fold increase in exciton density compared with the initial state of the sample.

"The terahertz pulse exposes the sample to an intense 1MV/cm^2 electric field," explains Hideki Hirori, team leader and assistant professor at Kyoto University's Institute for Integrated Cell-Material Sciences (iCeMS). "The resulting exciton avalanche can be confirmed by a bright, near-infrared luminescence, demonstrating a three-order-of-magnitude increase in the number of carriers," he adds.

Research at Kyoto using terahertz waves is led by professor Koichiro Tanaka, whose lab at the iCeMS pursues numerous applications including the development of new biological imaging technologies. "Since terahertz waves are sensitive to water, our goal is to create a microscope that will allow us to

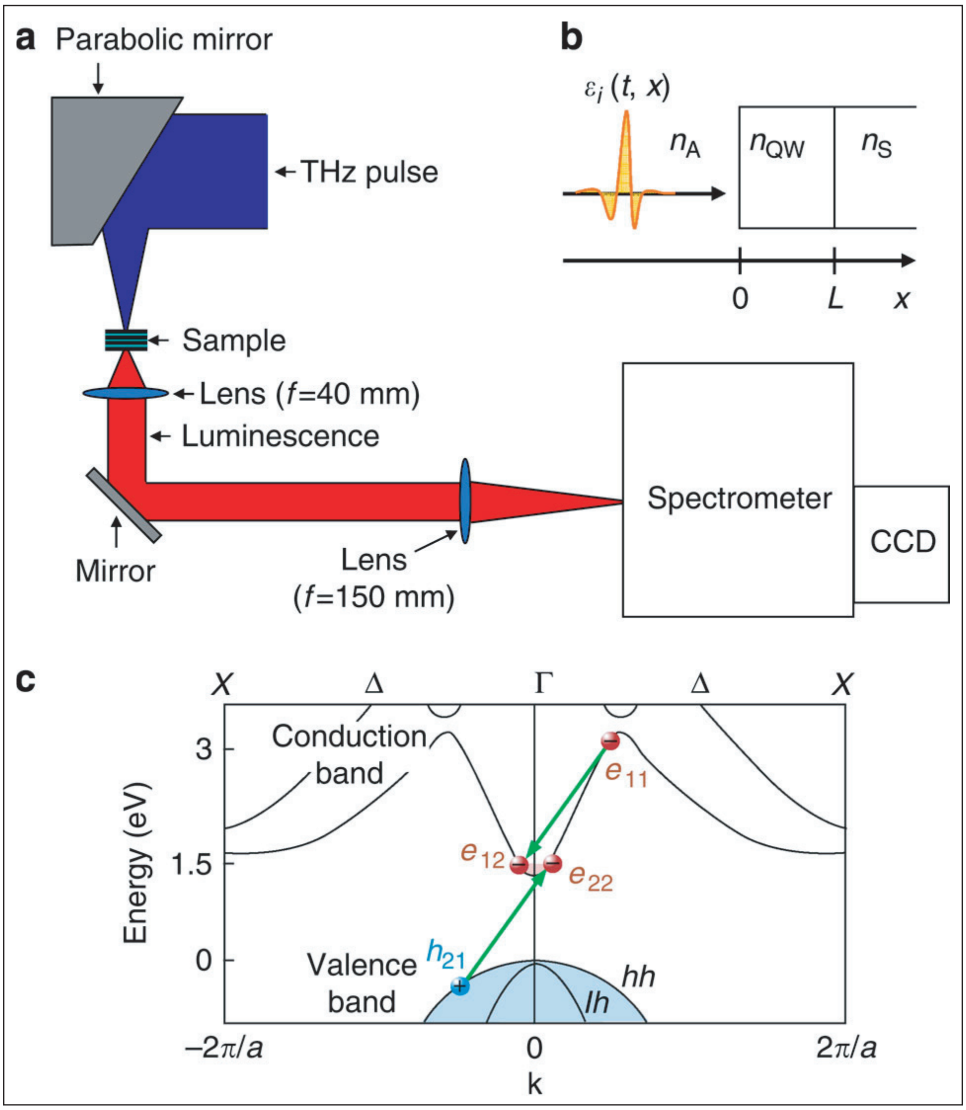

Figure 1: Measurement of THz pulse induced luminescence and impact ionization process. (a) Generated THz pulses are focused onto the GaAs QWs sample, and the luminescence is detected by a CCD camera after it has passed through a spectrometer. (b) The geometry of the sample interfaces with air (n_A=1), QWs (n_{QW}=3.5) and a quartz substrate (n_S=2.1). It is assumed that the QWs with thickness (L=6µm) on the quartz substrate has a homogeneous refractive index (n_{QW}=3.5) represented by the average of the refractive indices of the wells (n_w=3.6) and barriers (n_b=3.4). $\varepsilon_i(t, x)$ is incident THz electric field from the air. (c) Electron-initiated impact ionization transitions in the schematic GaAs band structure for momentum in the Δ direction. The lattice constant a of GaAs is 5.6Å, and ±2π/a corresponds to ±1.1x10^{10} m^{-1}. The diagram shows electrons and hole positions before and after the transition at the threshold.

look inside living cells in real time," says Tanaka. "These just-released results using semiconductors are an entirely different field of science, but they demonstrate the rich potential that lies in the study of terahertz waves," he adds.

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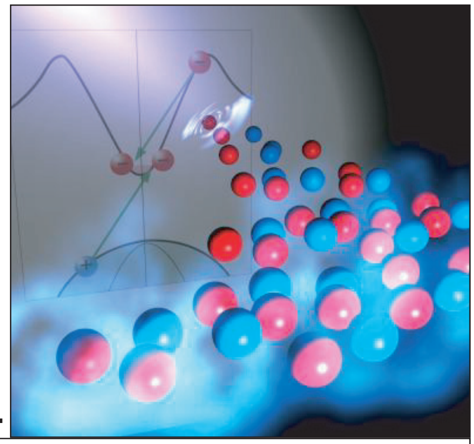

A picosecond THz pulse causes an avalanche of excitons from GaAs (right).

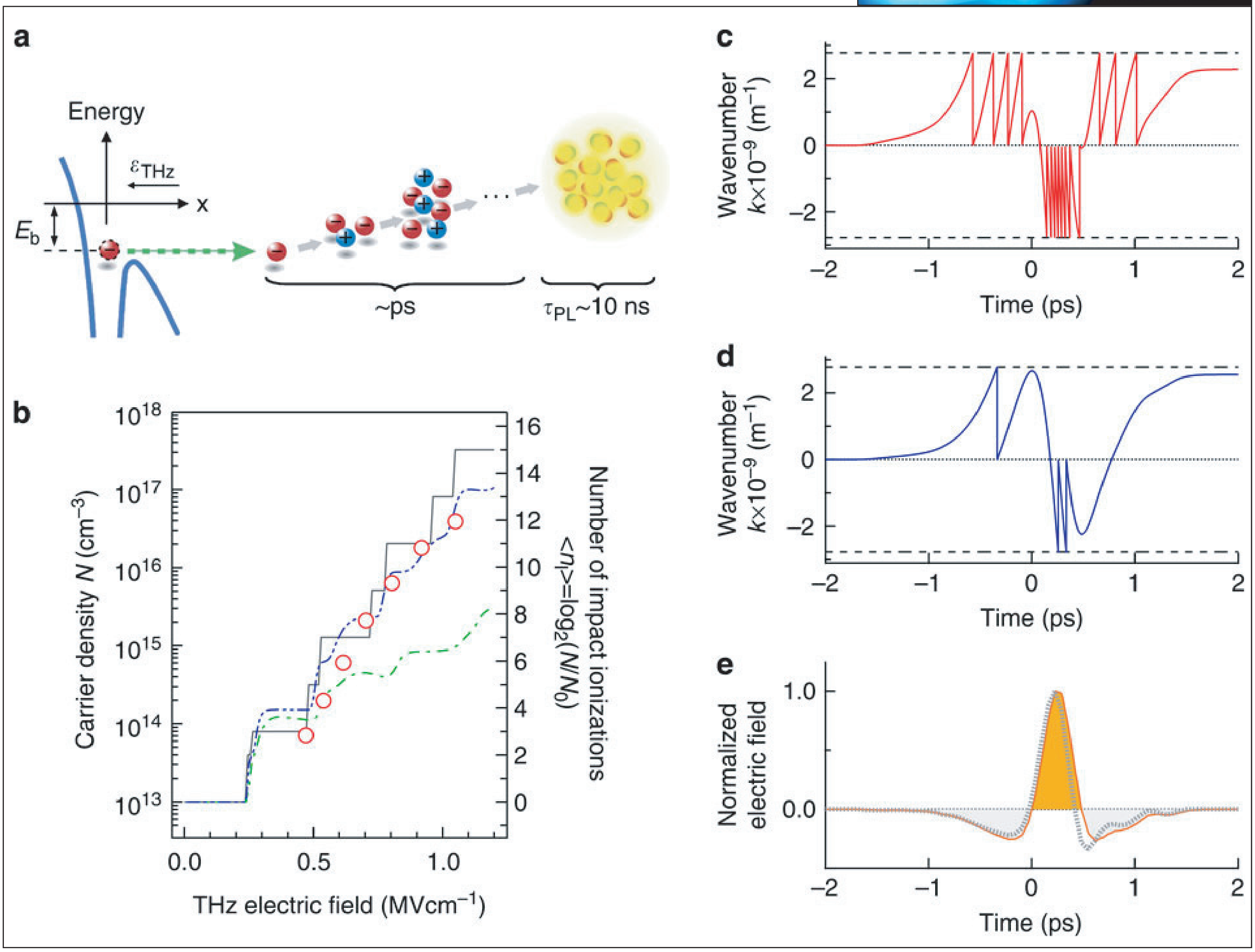

Figure 2: Comparison of experimentally and theoretically obtained carrier densities. (a) The sketch visualizes the distortion in the Coulomb potential of donors, causing the potential to widen and free electrons to be released, and subsequent evolution of unbound e-h gas generated by a series of impact ionizations into a pure population of excitons emitting luminescence. (b) Electric field dependences of carrier density obtained in the experiment (red open circle) and calculations for three different impact ionization rates γ_I^{cal}; one is infinity (grey solid line), and the others are derived with $C=C_0=870ps^{-1}eV^{-2}$ (green one-dot-dashed line) and $C=5C_0$ (blue two-dot-dashed line). It was assumed that $N_0=10^{13}cm^{-3}$. For the experimental (red open circles) and calculated data (grey solid line), the carrier density N is plotted together with the corresponding $<n_I>$. Panels (c) and (d) show the electron wavenumber k(t) calculated for ε=1.05 and 0.47MVcm^{-1}, respectively. Dashed lines indicate the wavenumbers in the range of ±2.77x10^{9}m^{-1}, where the electron energy corresponds to the threshold energy E_{th} of 1.7eV determined from the dispersion of the GaAs band structure. (e) Normalized electric field of the temporal profile of the incident THz pulse (grey dotted line) and of THz pulse with multiple reflections inside the sample (orange solid line).