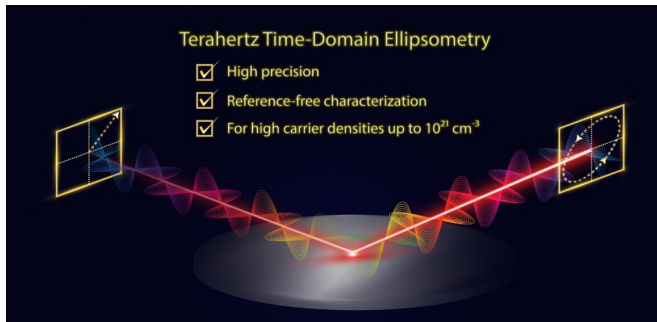


High-precision THz time-domain ellipsometry for wide-gap semiconductors

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Schematic image of Terahertz time domain ellipsometry. Credit: Osaka University

In semiconductor device applications, there is an increasing demand for semiconductors with very high carrier concentrations. The semiconductor material parameters, namely carrier density and mobility, primarily determine device performance. Hence, it is important to accurately characterize the carrier density and mobility of a semiconductor for the development of its device applications.

The use of THz waves, or [electromagnetic radiation](#) with wavelengths of around $300 \mu\text{m}$ and frequency of about 1 THz, in the nondestructive testing of semiconductors has been continuously expanding. Free carriers in a material absorb THz radiation, which makes it possible to estimate the electrical properties of semiconductors using THz waves.

Researchers at Osaka University, in collaboration with Nippo Precision Co., Ltd., developed a THz time-domain ellipsometry system (Tera Evaluator) that extends the range of [carrier](#) concentrations measurable by THz waves up to $\sim 10^{20} \text{ cm}^{-3}$ and potentially higher by improving the precision of said optical technique. In THz time-domain ellipsometry, linearly polarized THz pulses are incident on a sample and the [electric field](#) strength of the

reflected THz waves as a function of time is measured. Specifically, the reflected waves polarized in the direction parallel (p) and perpendicular (s) to the plane of incidence are of interest. The ratio of the p - and s -polarization components yields information on the electric permittivity of the sample, allowing for the evaluation of the carrier density and mobility. As such, unlike THz time-domain spectroscopy, THz time-domain ellipsometry does not require reference measurements through an aperture or standard mirror. Tera Evaluator employs a polarizer-sample-rotating analyzer optical configuration, wherein the analyzer angular orientation is varied from 0° to 360° in 15° increments. This multi-angle technique is used to eliminate the systematic errors from the amplitude and phase of the detected THz electric field in the analysis, which is newly employed in THz time-domain ellipsometry. This novel correction method improves the precision of THz time-domain ellipsometry by over ten times. Consequently, the maximum carrier concentration that can be evaluated is over 2 orders of magnitude higher than usually reported using other THz time-domain techniques.

As a demonstration, the researchers evaluated the gallium nitride (GaN) wide-gap [semiconductor](#), which is one of the most technologically important semiconductors present in various power electronics as well as 5G devices. GaN is also the leading candidate material for future 6G devices operating beyond 100 GHz. In a *Scientific Reports* publication, they show that the high-precision THz time-domain ellipsometry system is effective in the evaluation of carrier densities up to 10^{20} – 10^{21} cm^{-3} with superior accuracy and precision, which has been a challenge using THz waves, particularly at very high conductivities. The investigated GaN crystals were fabricated using a crystal growth method also developed at Osaka University called the point-seed technique via the Na-flux method, which produces high-quality GaN crystals.

The high-precision THz time-domain ellipsometry system is anticipated to be widely useful in the accurate, noninvasive characterization of various semiconductors with very high carrier concentrations.

More information: Terahertz time-domain ellipsometry with high precision for the evaluation of GaN crystals with carrier densities up to 10^{20} cm^{-3} , *Scientific Reports* (2021). [DOI: 10.1038/s41598-021-97253-z](https://doi.org/10.1038/s41598-021-97253-z)

Provided by Osaka University

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