THz radiation from delta-doped GaAs

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open circles present data at 0-V bias, the dots at -4 V.

Figure 1 shows a very clear bias dependence that disappears from 19-mW excitation as shown in Fig. 1b. The measured \( I_0 \) can be fitted to Eq. (1) very well with \( A_0 \), \( A_1 \) and \( A_2 \) as fitting parameters. The bulk contribution \( A_0 \) appears to be constant and insensitive to the applied bias voltage. This means that the bulk susceptibility is not affected by a depletion layer or injected carriers. The normalised interface contribution \( A_1 = A_1/A_0 \) depends on the effective electric field at the SB interface. \( A_0 \) appears to be proportional to the square root of the applied reversed bias and the zero-bias bandbending, in accordance with the Schottky model. From Fig. 1b it can be seen that the bias dependence of \( A_1 \) is much smaller for higher average laser powers. This power dependence can be explained by the effect of carrier injection. If generated holes reach the Au layer, the charges will be compensated to a certain extent and thus the effective electric field will decrease. This decrease of the field takes place on a femtosecond timescale. This means that the power dependence of \( A_1 \) also depends on the width of the laser pulses. Figure 2 shows the power dependence of \( A_1 \) measured at -4 V bias with a pulsewidth of 221 fs and 42 fs. Monte Carlo simulations performed to calculate this power and pulsewidth dependence are in qualitative agreement with these observations.

We show in Fig. 2 the rms values of the THz-pulses emitted from the delta-doped sample relative to the \( d = 25 \) nm sample as a function of delta-layer depth. The line represents a linear fit to the data.

The emission of ultrafast THz pulses from semiconductor surfaces after femtosecond laser excitation was recently observed by Zhang and Auston.1,2 Photonoexcited carriers created near the surface are accelerated by the electric field present due to surface band-bending. The resulting photo current radiates an electromagnetic pulse containing frequency components in the THz-regime. The presence of a delta-doped layer in the vicinity of the surface creates a very large field at the surface. These characteristics of the delta-doped structures make them very interesting as sources of THz-radiation, where both the high field and the high mobility should make the emitted THz amplitude greater than that emitted from bulk GaAs surfaces.

The delta-doped GaAs samples used in this work were grown by molecular beam epitaxy on Cr-doped semi-insulating GaAs substrates. The delta-doping was of n-type with Si as dopant. As reference samples we used a semi-insulating liquid-encapsulated Czochralski (LEC) GaAs sample. The fields present on both sides of the delta-doped layer are measured by photocurrent.

The experimental setup used in the THz experiments is described in Ref. 2. The THz signals radiated from the delta-doped samples upon laser pumping at 840 nm are shown in Fig. 1. The curves are labelled to indicate the type of sample. Also shown in a pulse radiated from the LEC GaAs reference sample. It is observed that the THz-pulses from the delta-doped samples show the opposite polarity of the THz-pulse emitted by the LEC GaAs sample. We also observe a decrease of the pulse amplitude as the distance from the surface to the delta-doped layer is increased.

The sign of the electric field radiated from the surface, and correspondingly the direction of the photocurrent, can be determined from the measured pulses by calibrating the response of the detection system with a biased THz-antenna. We find that the observed polarity of the pulses radiated from the delta-doped samples corresponds to a net current directed toward the substrate. This is consistent with the majority of the THz signal arising from the substrate side of the delta-doped layer.

We show in Fig. 2 the rms values of the THz-pulses emitted from the four delta-doped samples as a function of the position of the delta-doped layer. The straight line is a fit to the data and is explained in the following way: The source current responsible for the radiated THz-pulse originates from both sides of the delta-doped layer. Hence, the surface and substrate side contributions have opposite sign; the total THz signal is the sum of these contributions. As the distance from the surface to the delta-doped layer is increased the source current from the surface side is increased and the total THz-power is decreased.