THz detection with field-effect transistors

In terms of CW THz detectors, the most efficient and fast room-temperature operating detectors so far are Schottky diodes. They are very well engineered but hard to further improve. Within the last few years, rectifying field effect transistors (FETs) have emerged as an alternative to Schottky diodes. Fig 2 depicts a comparison of results from the literature of Schottky diodes and FETs, illustrating the saturation of the nose-equivalent power (NEP) of Schottky diodes but a rapid improvement of FETs.

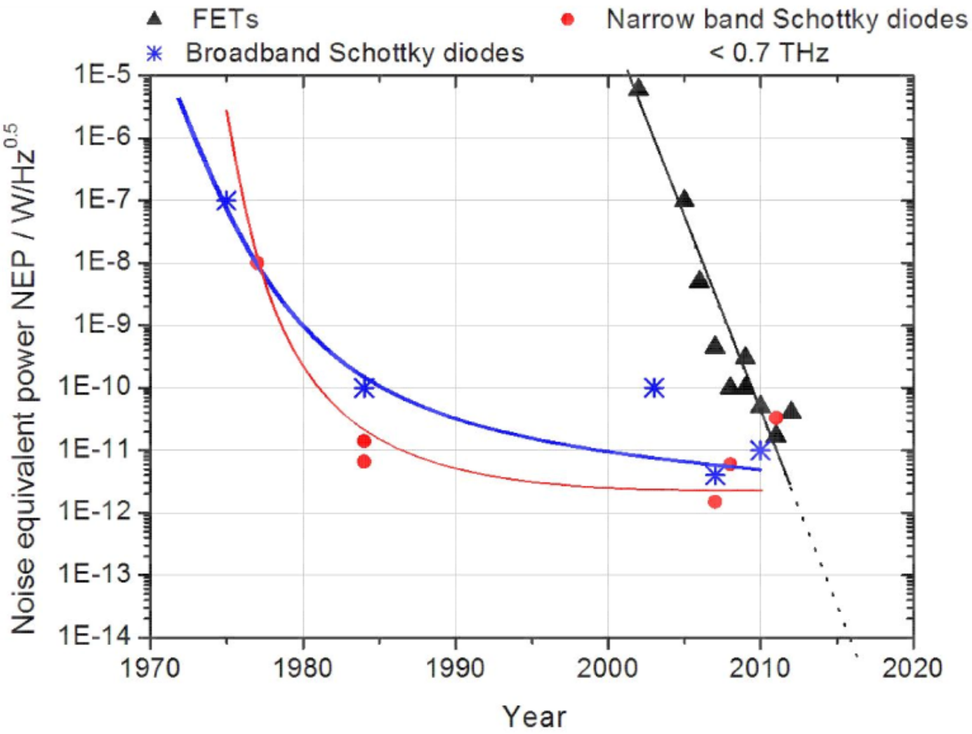

Fig. 1: Direct detection NEPs of Schottky diodes and FETs at room temperature, extracted from the literature.

A FET consists of a sheet of carriers (2DEG) that is connected to two ohmic contacts (source and drain). In between, a Schottky contact (gate) allows for repelling electrons under the gate as illustrated in Fig. 3. A gate bias can therefore be used to modulate the carrier concentration under the Schottky contact.

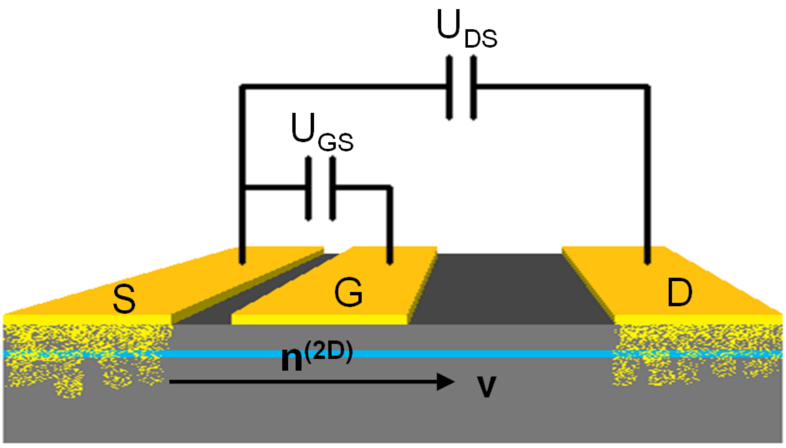

Fig. 2: Schematic of a FET

A rectification process in field effect transistors allows for generating DC biases from an incident THz signal, even if the THz frequency is much above its 3 dB frequency for amplification. The rectification results form *simultaneous* modulation of the carrier density, $n(t)$, by an incident THz field (of strength $E(t)=E\cos(\omega t)$) on the gate and the carrier velocity, $v(t)$, by the THz field that is coupled to the source-drain port. The current is proportional to the product of velocity and carrier concentration, $I(t)\sim v(t)n(t)$. Thus, a term proportional to the square of the THz field results, which contains a DC component, as $\cos^2(\omega t)=0.5+0.5\cos(2\omega t)$. The DC term can easily be measured. We investigate two types of FETs: 1.) lumped element devices that are coupled to an antenna, and 2.) large area, antenna-less detectors (LA-FETs).

For the latter, the direct interaction of the THz electric field with the carriers in the channel causes rectification. An array of very wide and narrow FETs in parallel connection cover an area in the range of the THz spot size as illustrated in Fig. 3. The array features an extremely small device resistance, allowing for operation at extremely high data rate. So far, we have detected signals at a data rate of up to 30 GHz, limited by the read out oscilloscope. The large area allows for very high THz power levels before failure occurs. Further, the GaAs-based LA-FET is sensitive to near IR pulses.

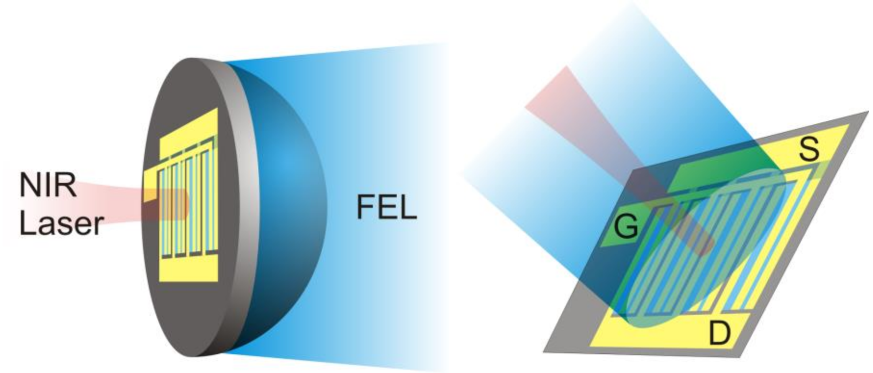

Fig. 3: Schematic layout of a LA-FET. Left: silicon-lens coupled device (typical cross section~0.3x0.3 mm²). Right: free space device (typical dimensions ~1.2x1.2 mm²).

The devices are designed for detecting high power THz radiation, such as free electron laser (FEL) signals, at highest possible temporal resolution. For most pump-probe experiments (THz pump-THz-probe, optical pump-THz probe), a reliable and fast detector is required to measure the temporal alignment between the pulses since there exists no natural locking between the FEL pulse and a NIR laser. Though the two lasers (FEL,NIR) can be operated at locked repetition rates, the displacement between the two types of pulses (i.e. the phase) is not known. A detector is required that is sensitive to both signals on a time scale of at least 100 ps. Electro-optic sampling (EOS), that is frequently used for table-top systems, is very unhandy for this application: Typical pulse widths are in the range of a few ps, but the pulses are ~10 ns apart. EOS would require ~10 000 time steps in order to reliably measure the temporal alignment.

LA-FETs are ideal tools to pre-align optical pump-THz-probe experiments. A fast oscilloscope can be used to measure the time delay between a THz and a NIR pulse. The temporal alignment can be measured within ~ 1 s at an accuracy in the range of ~50-100 ps as shown in Fig. 4.

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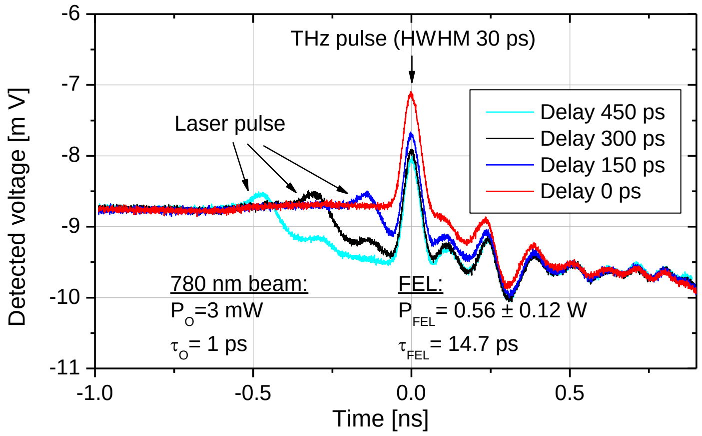

Fig. 4: Synchronous measurement of a free electron laser pulse and a NIR laser pulse with a LA-FET and a 30 GHz oscilloscope. [Link zum Paper]

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