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Femtosecond electron beam probe of ultrafast electronics

Maximilian Mattes[1], Dr Mikhail Volkov[1], Prof Dr Peter Baum[1]
[1]Universität Konstanz, Konstanz, Germany

Background and Experiment

The need for ever-faster information processing requires exceptionally small devices that operate at frequencies approaching the terahertz and petahertz regimes. However, electronics itself is too slow to characterize a record-breaking device. Here we show how ultrafast electron beam probe with terahertz-compressed electron pulses can directly sense local electro-magnetic fields in electronic devices with femtosecond, micrometre and millivolt resolution under normal operation conditions [1].

Figure 1 shows the concept of our experiment. We use a femtosecond laser (red) that creates femtosecond electron pulses (grey) with only one electron per pulse. This electron pulse is then further shortened in time to less than 100 fs by using all optical terahertz compression [2]. These ultrashort electron pulses probe the local electromagnetic fields in our device under test (DUT), which is shown in Figure 1. We create a short voltage pulse by exciting a photoconductive switch. The generated femtosecond voltage pulses (magenta) travel through our device under test and the device response deflects the electron beam as a function of space and time. From the resulting electron beam deflections, we then obtain the strength and direction of the local electromagnetic fields [1]. The electron beam does not distort the dynamics under investigation and the measurement is therefore contact-less and impedance-free.

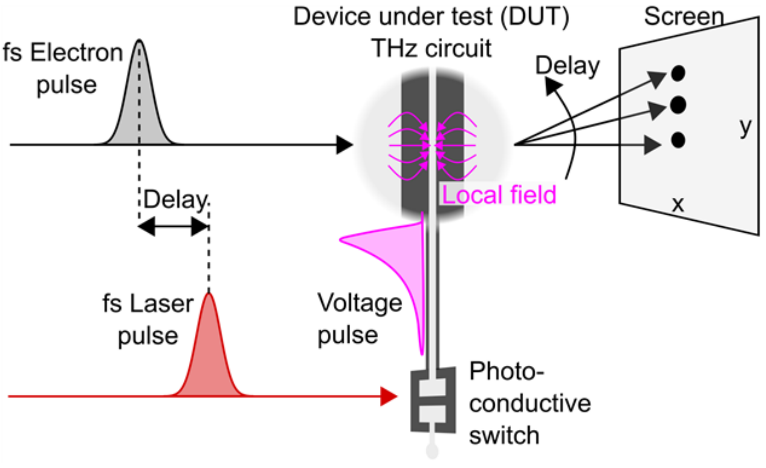
Results and outlook

In a proof of principle experiment, we investigate a coplanar waveguide which is the standard transmission line in high-frequency electronics. We fabricate the structure by lithography and drill two holes into the substrate for investigation. We observe the impulse response, signal reflections, attenuation and waveguide dispersion directly in the time domain. We find that the experiment has a sensitivity to electric potentials down to tens of millivolt or -20 dBm. With our 100-fs electron pulses, the bandwidth exceeds 10 THz which is well sufficient for almost any modern or near-future circuitry. In order to eventually obtain a full movie in space and time, we also report the design of an ultrafast transmission electron microscope with terahertz compression [3]. The use of an optical cavity with magnetic or electric nodes at the point of electron-terahertz interaction provides an almost aberration-free control. In this way, we can reach nanometer spatial resolution and reach even shorter electron pulse lengths down to 19 fs [3].

Our femtosecond time resolution and the capability to directly integrate our technique into existing electron-beam inspection devices in semiconductor industry make our femtosecond electron beam probe a promising tool for research and development of next-generation electronics at unprecedented speed and size.

Fig. 1. A laser pump pulse (red) creates a voltage pulse (magenta) by closing a photoconductive switch. This pulse then travels into the device under test and triggers its operation. Femtosecond electron pulses (grey) probe the local electric and magnetic field (magenta) [1].

Graphic:



Keywords:

Ultrafast electron microscopy, THz electronics

Reference:

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