

TCAD simulations of the SEBAT employed as readout for color centers in diamond

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Abstract: We present the Single Electron Bipolar Avalanche Transistor (SEBAT), enabling room-temperature single-electron detection from NV centers based on TCAD simulations to optimize microfabrication process and design parameters such as electric field, breakdown and transient response.

We report on a Single Electron Bipolar Avalanche Transistor (SEBAT) for the detection of single electrons emitted at room temperature by Nitrogen Vacancy (NV) centers in diamond. In the context of quantum computation, one of the objectives is to advance the state of the art of Photocurrent Detection Magnetic Resonance (PDMR) techniques, by developing Single Shot Readout (SSR) of the qubit spin state reading the current emitted by the NV center using SEBAT device coupled to the diamond chip through 3D integration techniques. Compared to traditional optical readout methods, the SEBAT will allow amplification of the small photocurrent generated from the NV centers, exploiting its Geiger mode avalanche multiplication, which can provide an internal gain in the order of 10^6 for the single electron. A conceptual half cross-section is shown in Fig.1. Furthermore, because of its large bandwidth typically above 1GHz [1], the SEBAT appears suitable for applications that require a fast response time. In analogy with a Single Photon Avalanche Diode (SPAD) that can perform single photon detection, the SEBAT can count the avalanche events triggered by single injected electrons from the emitter into the base of the transistor and provide a straightforward analog-to-digital conversion of the output signal. Thanks to the compact size of the device, it will be easy to integrate the NV center + SEBAT with electronic readout boards. To investigate the SEBAT design, TCAD device and process simulations were performed to evaluate the best set of parameters for the device and to study the electric field, breakdown voltage and dark currents at different operating conditions. Another set of simulations examined the transient behavior, by injecting a charge in different positions inside the structure and evaluating the injection efficiency from the emitter into the base region and the subsequent triggering probability of an avalanche in the base-collector junction. A SNR model has been considered for a given input electron rate originating from the NV center in diamond and entering the SEBAT from the emitter. The role of the emitter capacitance on the overall integration time was investigated, showing that it is a key parameter affecting the time response of the SEBAT and the SNR, when used in conjunction with the NV center.



Fig.1 SEBAT cross section

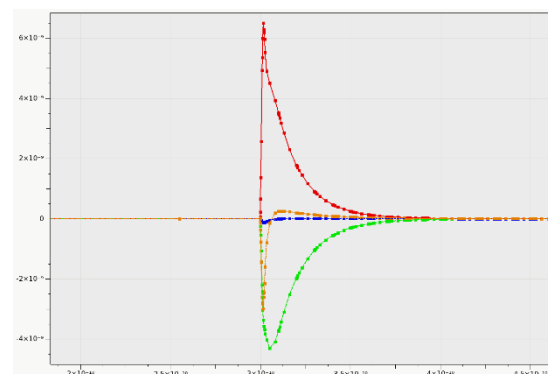


Fig.2 Transient currents

References

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- [2] Quarta G., Perenzoni M., Pancheri L., "SEBAT-Based Readout for FET THz Detectors With Intrinsic Power-to-Frequency Conversion", *IEEE Sens. J.* **22:8**, 7763-7771 (2022)