A solid-state quantum voltage reference| 10GS	**Start Date:** August 1st 2016
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Abstract: There is no existing portable reliable voltage standard. Existing voltage references are derived from hybrid diode arrangements. Those structures are specified in terms of their initial output voltage accuracy, their temperature coefficients and their short and long-term drifts. Despite tremendous progress in fabrication techniques, temperature compensation and drift correction over almost a century, current devices achieve accuracies on the order of 10^{-4}, temperature coefficients of 10^{-5}/K, drift of 10^{-5}/kh and relative noise levels of 10^{-6}, and they are usually shipped uncalibrated. Yet, there is a growing need for calibration-free voltage references as, e.g. all digital to analogue conversion requires a reliable base voltage.

The project aims at exploring optically accessible spin defects in silicon carbide (SiC) and diamond as quantum voltage standards. The electric field generated by the voltage to be referenced should be measured via a precision measurement of the spin splitting of such atomic scale defects, which arises from spin orbit coupling. Superior functionality is expected mainly because of four facts. First, electric fields effectively break defect or lattice symmetry and therefore can be uniquely identified. Second, compared to current devices they do not rely on the Boltzman factor $\exp(-E/k_BT)$ and are therefore much less prone to temperature variation. Particularly, the defect center electric field measurements are largely immune against temperature effects for symmetry reason. Third, proper functionality is envisaged beyond certain limits of crystal quality, whereas current devices have to precisely match certain criteria, e.g. doping levels. Fourth, the long-term stability is expected to be superior because the applied electric fields in the envisaged quantum standards are well below the discharge field strength whereas state-of-the-art devices work close to or above these fields, which causes avalanches and ageing. Interestingly, such a quantum voltage standard can reference a continuously tuneable voltage.

In proof-of-principle measurements, we showed the possibility to measure electric fields using single and ensembles of NV centers in diamond (see Fig. 1). Here, low strain, synthetic diamond lead to long coherence times of T_2>700 µs, thus increasing electric field sensitivity. Furthermore, developed a novel measurement scheme combining classical lock-in detection and quantum phase estimation to achieve both, a high level of noise rejection and a very accurate electric field (Fig. 2). Consequently, we have achieved an electric field sensitivity of up to 10^{-6} V/µm (see Fig. 3).

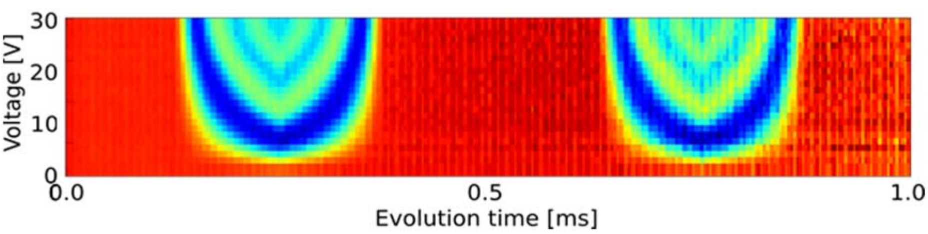

Fig 1: Spin-echo signal for varying AC electric field strength and echo duration. The signal pattern reveals strength and shape of the ac waveform.

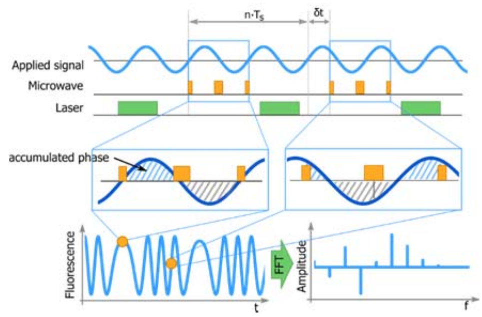

Fig. 2: Precision amplitude measurement scheme: The accumulated quantum phase in a spin-echo sequence depends on the relative phase of the ac electric field. This enables precise frequency measurements and finally lock-in detection of the ac signal-strength. As the spin-echo signal is a highly non-linear function of the electric field strength, higher orders of the electric field frequency appear. We compare their amplitudes for accurate field estimation.

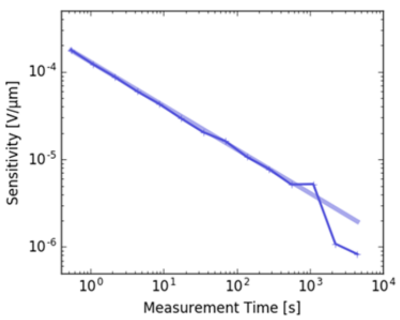

Fig. 3: Scaling of electric field uncertainty over measurement time. The straight line corresponds to a scaling of $1/\sqrt{\text{Hz}}$. Owing to our novel measurement technique effects of long term drifts of the measurement apparatus (e.g. laser, detectors, temperature and magnetic fields) could be suppressed.

Recent results:

- *Successful measurement of AC electric fields with an NV center ensembles in diamond*
- *Combination of classical lock-in detection and quantum phase estimation for accurate amplitude measurements of ac fields*
- *Recent results enable development of concepts for miniaturization*

Publications:

Talk at DPG Spring meeting:

"Precision measurements of electric fields using NV centers in diamond"

paper in preparation

Further Collaborators:

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