Enhanced metrology using preferential orientation of nitrogen-vacancy centers in diamond
Supplemental Material

I. OTHER CONTRIBUTIONS TO AC MAGNETIC FIELD SENSITIVITY

Samples A and B were chosen for this work because they are similar in most aspects excepting the presence or absence of preferential NV orientation. However, the two samples are not identical; they differ slightly in isotopic composition, NV density, and spin coherence time. Therefore, in order to properly compare the effect of preferential NV orientation on ac magnetic field sensitivity, we must perform a detailed analysis of the contributions from these other differences.

The optimum AC magnetic field sensitivity is given in the main text by Eq. 1, which can be re-written as:

$$\eta \approx \frac{\pi \hbar}{2g\mu_B} \frac{1}{C_0 \exp\left[-(\tau_{\mathrm{ac}}/T_2)^p\right]} \frac{1}{\sqrt{\tau_{\mathrm{ac}} n_{\mathrm{photon}}}} \tag{1}$$

The Eq. 1 parameters $C(T)$, which depends on factors such as optical collection efficiency and measurement contrast, and n_{NV}, the number of NV spins contributing to the measurement, are here recast in terms of contrast and number of NV fluorescence photons collected per measurement. The contrast term consists of the initial measurement contrast C_0 and the reduction in measurement contrast due to decoherence characterized by T_2 and exponential power p. The number of NV fluorescence photons collected per measurement n_{photon} depends on the number of NV spins contributing to the measurement, collection efficiency, and factors such as excitation laser power and optical read-out pulse duration. We now consider the contributions of differences in sample isotopic composition, NV density, and spin coherence time separately.

A. Isotopic composition

Sample B was isotopically engineered to contain 0.01% ^{13}C, whereas Sample A has a natural abundance (1.1%) of ^{13}C. As mentioned in the main text of the paper, the higher concentration of ^{13}C in Sample A results in periodic collapses and revivals characteristic of ^{13}C Larmor precession in the coherence curve [Fig. 3(a)]. By performing measurements on an ac magnetic field with a frequency corresponding to the center of a revival (or alternatively, by applying a static magnetic field such that the center of a revival corresponds to the frequency of the ac magnetic field one desires to measure), the collapses and revivals may be ignored, and only the affect of ^{13}C on the decoherence envelope need be considered.

We also note although the lattice parameters of isotopically varied diamond samples are quantitatively different, the growth morphology for these particular samples is dominated by the growth conditions and especially the addition of nitrogen. As such, there is no distinguishable effect from the ^{12}C diamond lattice parameter on the growth morphology of these samples.

B. Coherence time

In Figure S1, the NV spin decoherence curves are replotted in terms of coherence rather than contrast. From the fits to the decoherence envelope (Sample A) and curve (Sample B), we extract fit parameters $T_2 = 479 \pm 2\mu$s and $p = 2.46 \pm 0.04$ for Sample A, and $T_2 = 527 \pm 1\mu$s and $p = 2.01 \pm 0.02$ for Sample B. Even though there are small differences in the decoherence behavior of the samples, the actual coherence levels at the time $\tau_{\mathrm{ac}} = 324.416\mu$s corresponding to the frequency of the applied ac magnetic field are quite similar: 0.682 for Sample A and 0.697 for Sample B, as calculated from the fits. Thus we expect that the difference in NV spin coherence time between the two samples will contribute to a factor 1.022 improvement in the sensitivity of Sample B compared to that of Sample A.

C. NV density

The NV densities of Samples A and B were determined from the NV fluorescence measured using a scanning confocal microscope and were found to be NV $\sim 5 \times 10^{12}$ cm^{-3} for Sample A, and NV $\sim 3 \times 10^{12}$ cm^{-3} for Sample
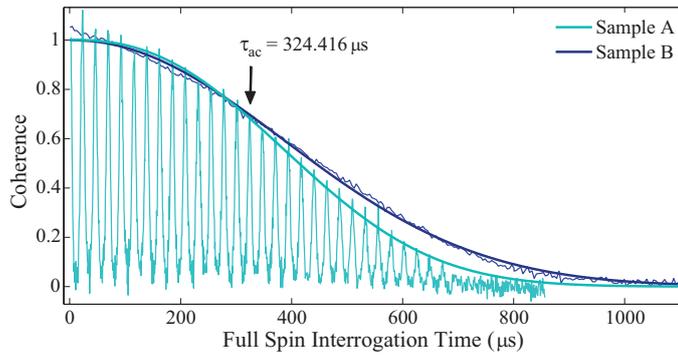
FIG. S1: NV spin coherence decay of Samples A and B normalized in terms of coherence, where the thicker lines denote fits to the decoherence envelope of the form $\exp\left[-(t/T_2)^p\right]$. The ac magnetic field period τ_{ac} is indicated with an arrow.

B. To compensate for these differences in NV densities, for each sample we chose a laser power and optical read-out pulse duration which both optimized the measurement contrast and yielded as similar a number of NV fluorescence photons collected per measurement n_{photon} as possible without deviating from optimum measurement contrast. By applying different laser powers and optical read-out pulses to each sample according to these criteria, we collected $n_{\mathrm{photon}} \approx 0.186$ photons per measurement for Sample A and $n_{\mathrm{photon}} \approx 0.204$ photons per measurement for Sample B. As a result, we expect that the difference in n_{photon} between the two samples will contribute to a factor 1.047 improvement in the sensitivity of Sample B compared to that of Sample A.

D.   Summary

We measured AC magnetic field sensitivity (in a 6μm $\times$ 6μm $\times$ 50μm detection volume) to be $6.1 \pm 0.2\mathrm{nT}/\sqrt{\mathrm{Hz}}$ for Sample A and $2.6 \pm 0.1\mathrm{nT}/\sqrt{\mathrm{Hz}}$ for Sample B, corresponding to a factor 2.3 ± 0.1 difference in measured sensitivity. The combined effect of the small differences in spin coherence time and NV density between the two samples gives a factor 1.07 improvement in the sensitivity of Sample B compared to that of Sample A. Removing these contributions from the measured sensitivity still yields a factor > 2 improvement in the sensitivity of the preferentially oriented Sample B compared to the standard Sample A.