ULTRA HIGH SENSITIVITY NMR: 1-MM HTS TRIPLE RESONANCE PROBE

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We report a 600-MHz 1-mm triple-resonance high-temperature-superconducting (HTS) probe for NMR spectroscopy. The probe has a real sample volume of about 7.5 μl, an active volume of 6.3 μl, and appears to have the highest mass sensitivity at any field strength. The probe is constructed with 4 sets of HTS coils that are tuned to $^1$H, $^2$H, $^{13}$C, and $^{15}$N, and there is a z-axis gradient. The $^1$H coil pair has two features that allow it to be placed very close to the sample: First, the resonators, based on two distributed interdigital capacitors, with a spatial periodicity of only 0.125 mm, place a very low fringing electric field on the sample. Second, the current-carrying fingers are extensively slit to reduce shielding currents that would reduce $B_0$ homogeneity. The $^1$H coil pair also has a large height-to-width ratio to produce a homogeneous RF field. The $^2$H and $^{13}$C coils are spiral resonators. Lock sensitivity with such a small sample volume was given higher priority than carbon observe sensitivity, and for this reason the $^2$H coils are in the second position from the inside, and the $^{13}$C coils are in the third position. On the outside are the $^{15}$N coils, also spiral resonators to achieve a resonance frequency of 60 MHz.

Because the $^{15}$N coils are far from the sample, their rather large electric field is acceptable. However, the simple spiral design supports additional modes at approximate multiples of 60 MHz. Final frequency-trimming relied upon extensive simulations to prevent these modes from interfering with the other coils. The coils are cooled with a conventional Bruker CryoPlatform to about 20 Kelvin, and the sample chamber can be regulated above or below room temperature over a moderate range using a Bruker variable temperature unit. The S/N value of 292±28 for 0.1% ethylbenzene is approximately 3.5-fold less than a standard 600 MHz 5-mm triple-resonance probe (S/N ~1000) with about 70-fold less sample. Thus, the mass sensitivity of the 1-mm HTS probe is about 20 times greater than a conventional 5-mm probe. Commercial 5-mm Bruker 600 and 800 MHz cryoprobes have S/N values approximately 4000 and 8000, respectively. The 1-mm HTS probe has a mass sensitivity that is over 4 times greater than a 5-mm cryogenic probe at the same field strength and over 2 times greater than state-of-the-art 5-mm technology at 800 MHz.

The extremely high mass sensitivity of this probe suggests that it may be useful for metabolomics, natural products, and protein screening applications. Figure 1 demonstrates the utility of this probe for small molecules and proteins with a 2D spectrum of 400 μM $^{15}$N-labeled ubiquitin in 8 μl phosphate buffer (pH 5.5) with 10% D2O for lock.

Figure 1. Experimental data from the 1-mm HTS triple-resonance probe. Data were collected using 400 μM ubiquitin using gradient 15N-HSQC and were recorded in 41 m using 16 scans and 128 $t_1$ increments. High quality data on 8 μL 1 mM samples can be obtained in about 10 min (not shown).

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References

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