We have recently found a way to suppress the vortex signal in anisotropic type II superconductors, and measure the London penetration depth directly while applying a magnetic field. Our method requires that the sample is placed in the coil of a tunnel diode oscillator with the oscillating magnetic field oriented perpendicular to the most conducting layers. In this orientation the penetration depth is measured in the conducting planes. The key to our method is to orient the applied dc magnetic field parallel to the conducting layers. Often, the applied magnetic field needs to be aligned better than a degree. Depending on the anisotropy of the superconductor, the vortices parallel to the conducting layers will be large and weak because they will reside in the least conducting planes of the sample. The rf field will try to move the vortices in the direction perpendicular to the conducting planes, but in this direction the conducting planes will intrinsically pin the vortices reducing any vortex related penetration depth signal to zero. However, the vortices will still be able to move in and out of the sample with no effects of intrinsic pinning by moving parallel to the conducting planes.

A good example proving that our method removes the effects of vortices is the case of $\kappa$-(ET)$_2$Cu(NCS)$_2$. Figure 1 shows the penetration depth signal as a function of angle. The bumps, oscillations and hysteresis in the penetration depth signal are real, and represent vortex pinning and avalanches[1, 2]. Notice that at exactly 90° (lowest trace), the vortex signals are absent. At this angle we only measure the London penetration depth for the reasons described above.

In the case of $\kappa$-(ET)$_2$Cu(NCS)$_2$, the penetration depth signal shows a power law behavior suggesting that there are no nodes in the gap. This result, showing no nodes, adds to the controversy surrounding the question of the nature of the order parameter in $\kappa$-(ET)$_2$Cu(NCS)$_2$ [3]. One may question these results because of the possibility of a bad background measurement, but a second aspect of the measurement supports the absence of nodes. Comparing the magnitude of the penetration depth to the d-wave superconductor CeCoIn$_5$ [4] and the s-wave superconductor $\alpha$-(ET)$_2$NH$_4$(SCN)$_4$ [5] we find that there is only a small amount of penetration in $\kappa$-(ET)$_2$Cu(NCS)$_2$ similar to $\alpha$-(ET)$_2$NH$_4$(SCN)$_4$. The nodes in CeCoIn$_5$ increase the overall amplitude of penetration. In $\kappa$-(ET)$_2$Cu(NCS)$_2$ the total penetration is small, again supporting no nodes.

In a separate part of this experiment we measured the magnetic breakdown effect in the title material down to 50 mK.

We acknowledge the NSF-DMR-0331272 and the NHMFL for support.

References