Electric Field Assisted Self-Healing of Open Circuits with Conductive Particle-Insulating Fluid Dispersions: Optimizing Dispersion Concentration

Supplemental Material

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S1. SELF-HEALING WITH DIFFERENT TEMPERATURE

A. 30 degree Celsius

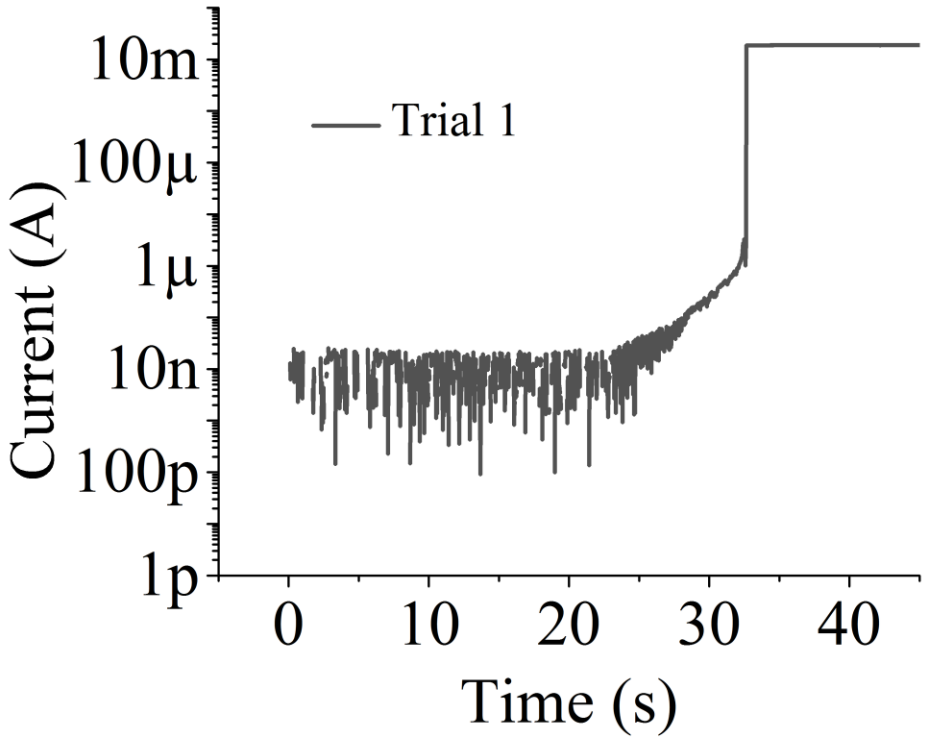


FIG. S1. Concentration = 25 mg/ml

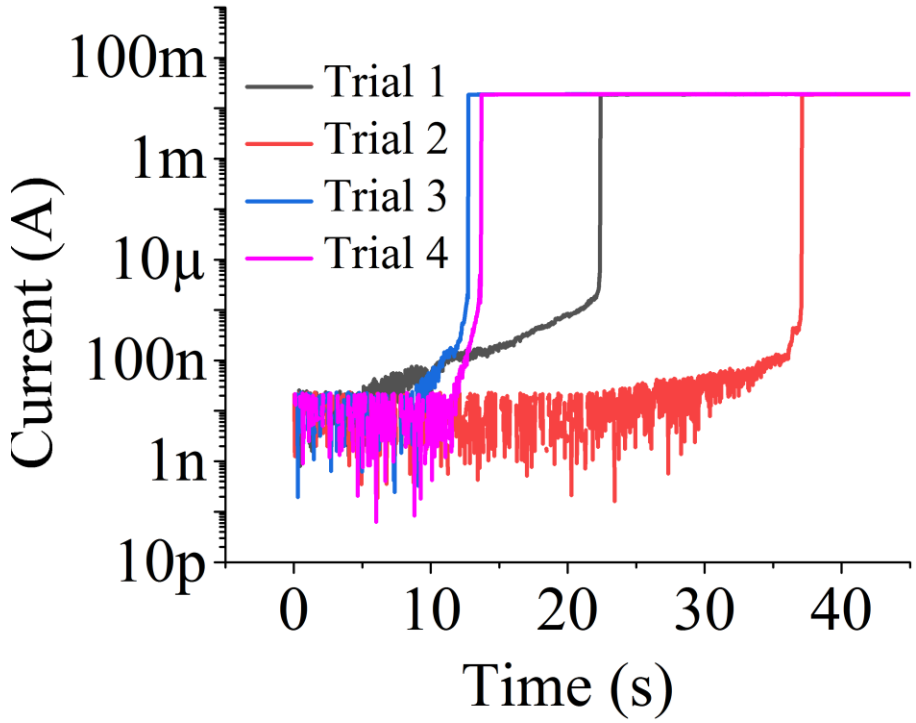


FIG. S2. Concentration = 50 mg/ml

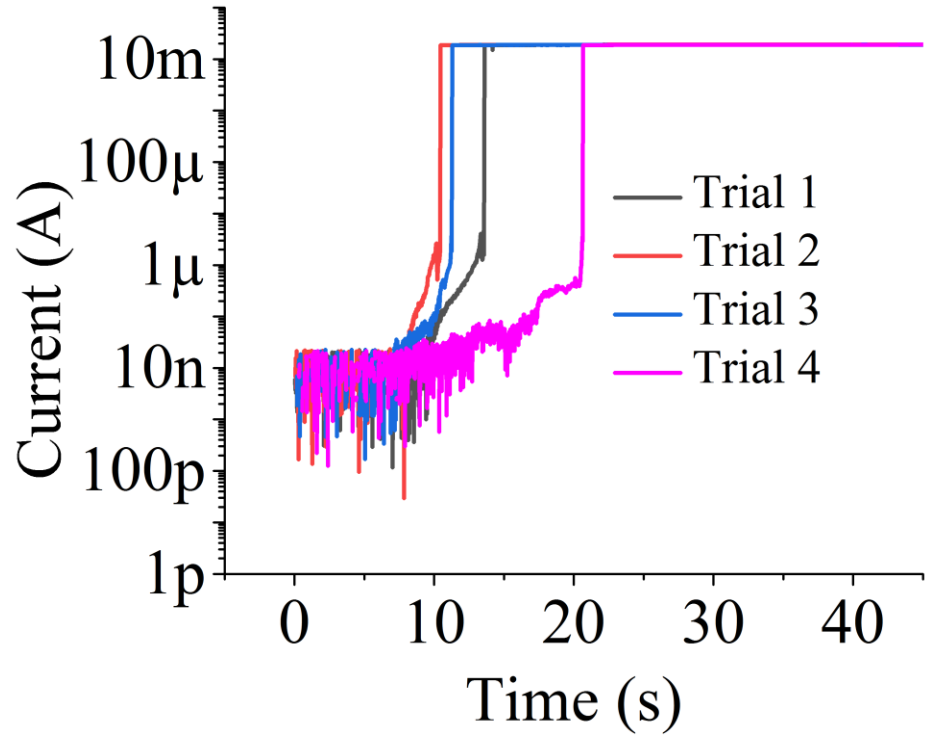


FIG. S3. Concentration = 75 mg/ml

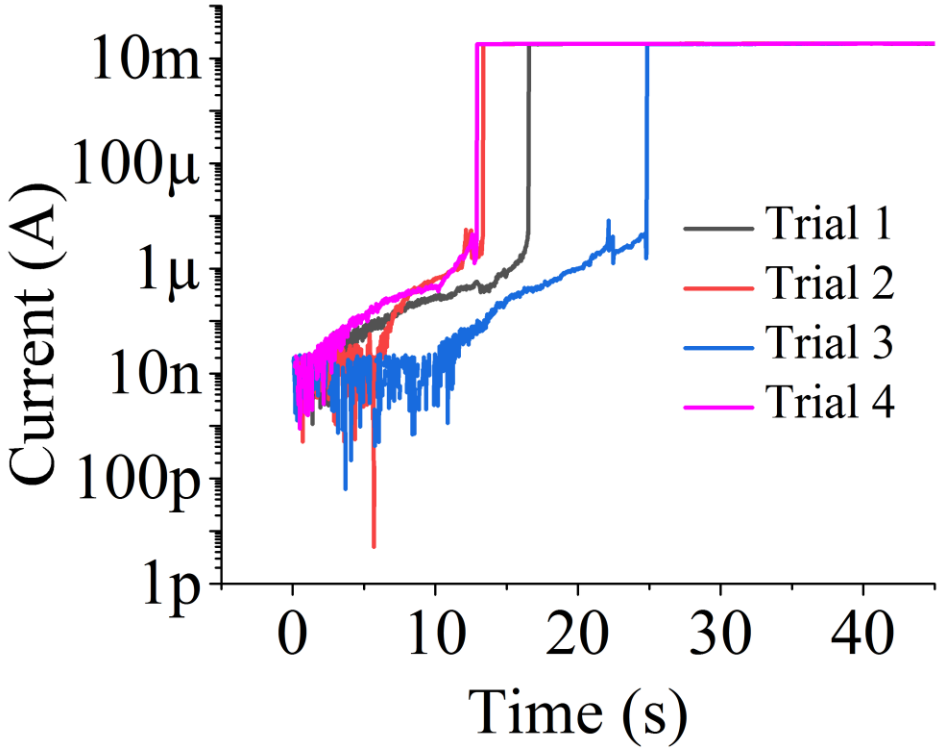


FIG. S4. Concentration = 100 mg/ml

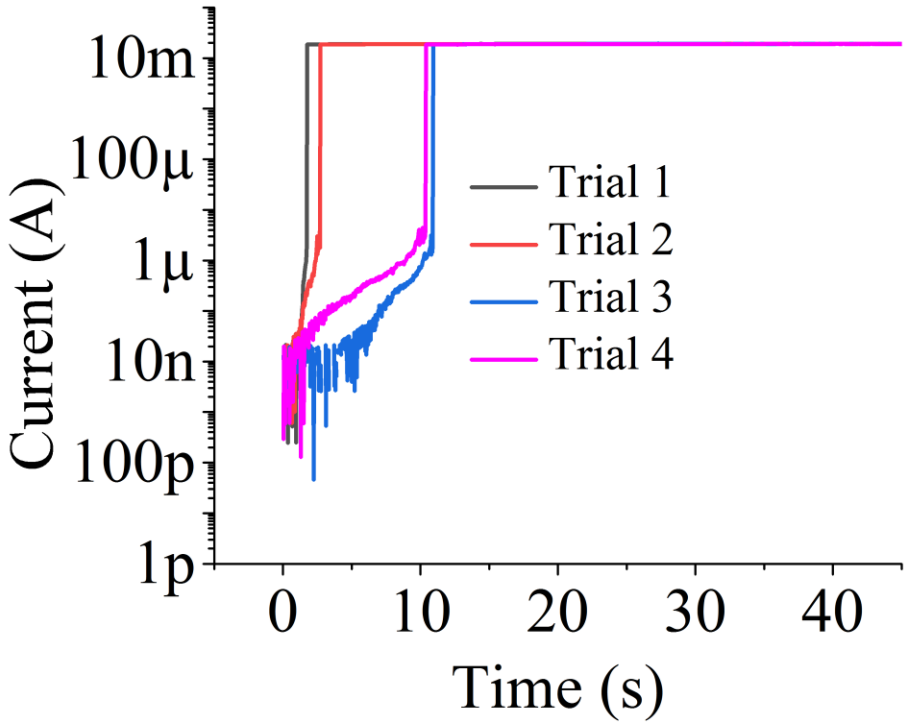


FIG. S5. Concentration = 125 mg/ml

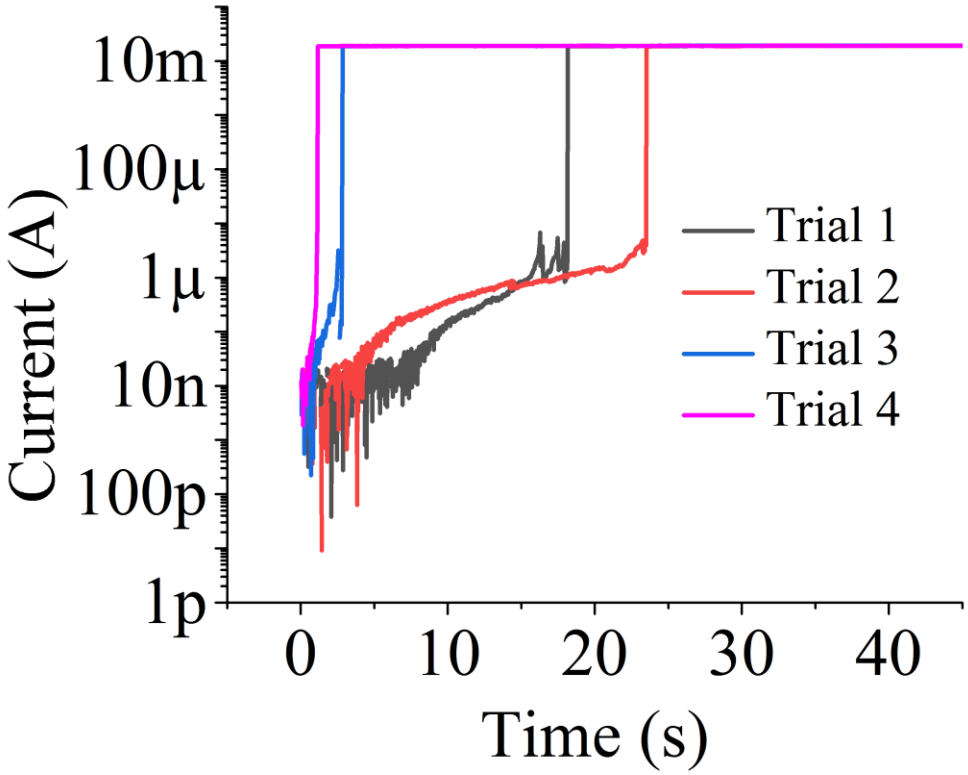


FIG. S6. Concentration = 175 mg/ml

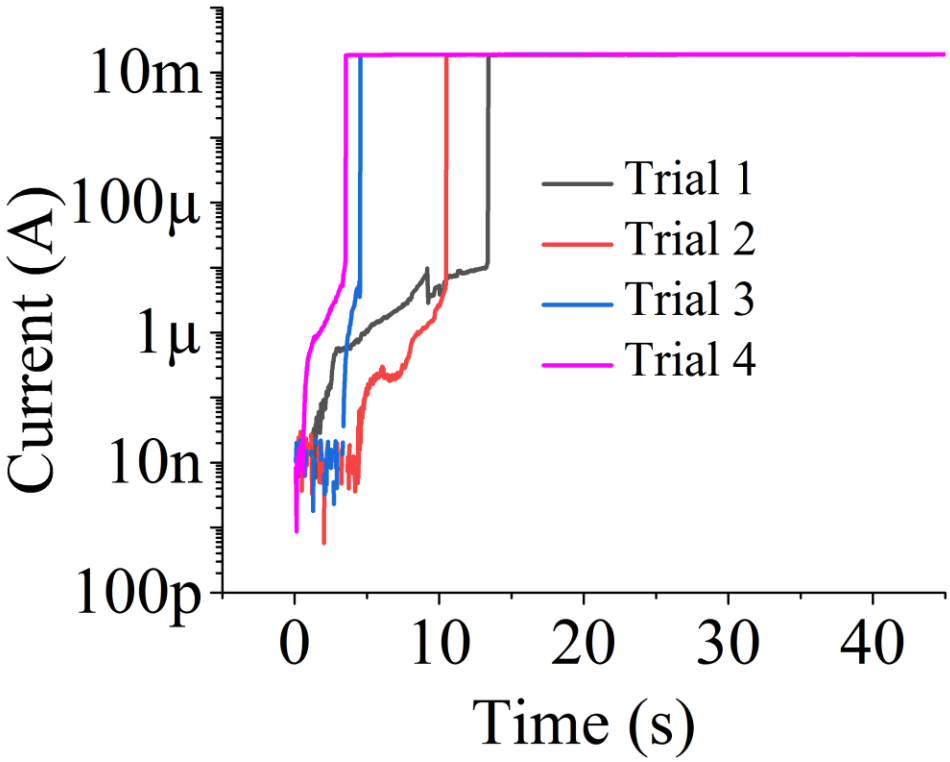


FIG. S7. Concentration = 200 mg/ml

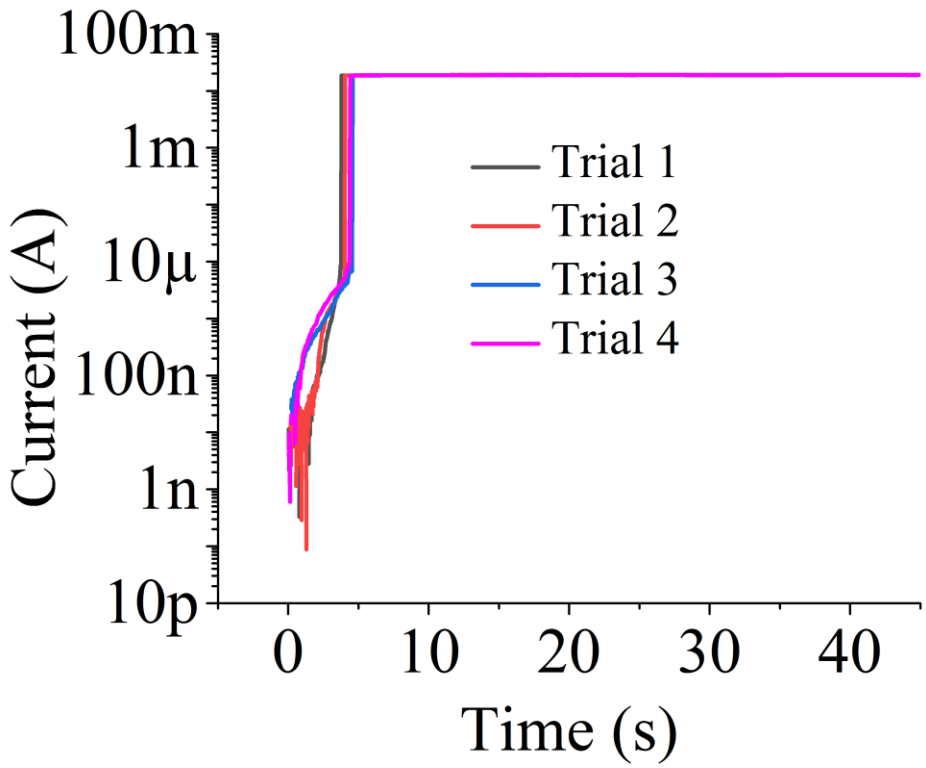


FIG. S8. Concentration = 250 mg/ml

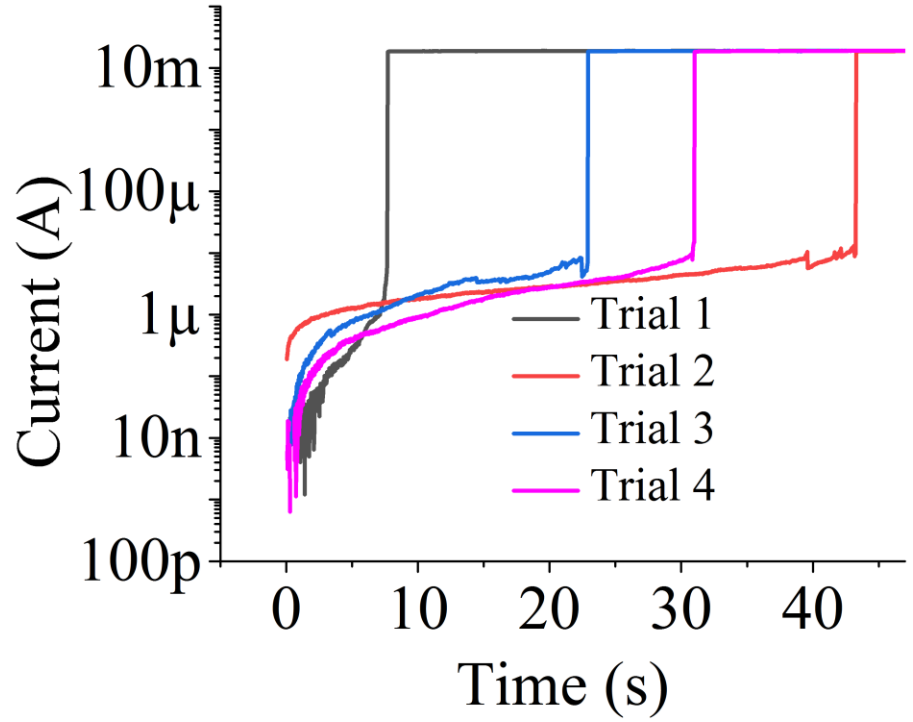


FIG. S9. Concentration = 300 mg/ml

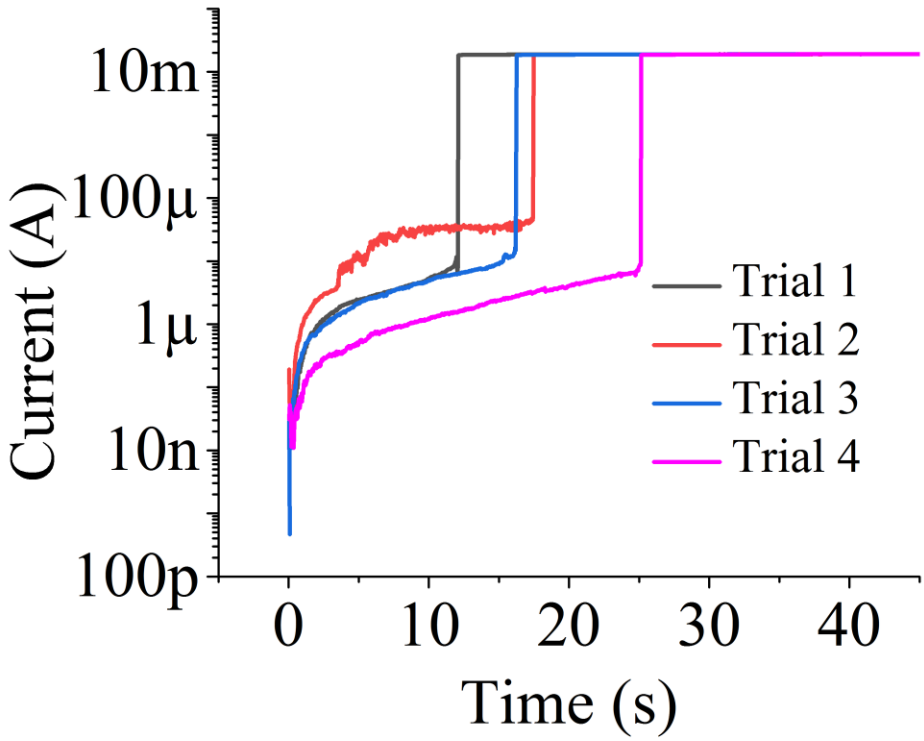


FIG. S10. Concentration = 350 mg/ml

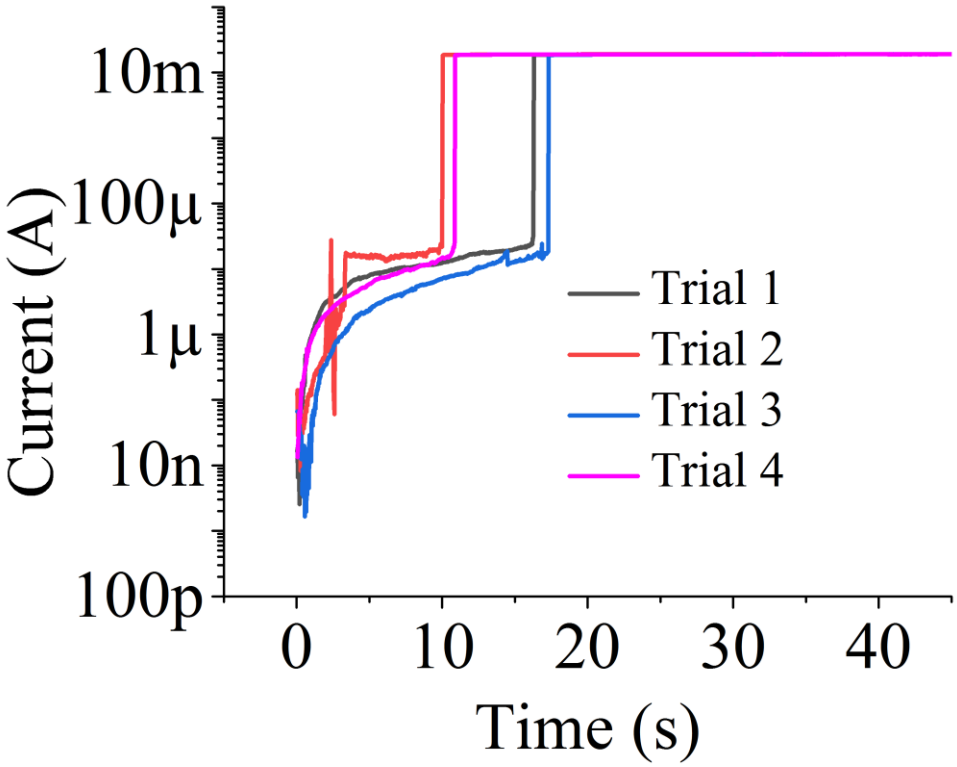


FIG. S11. Concentration = 400 mg/ml

B. 40 degree Celsius

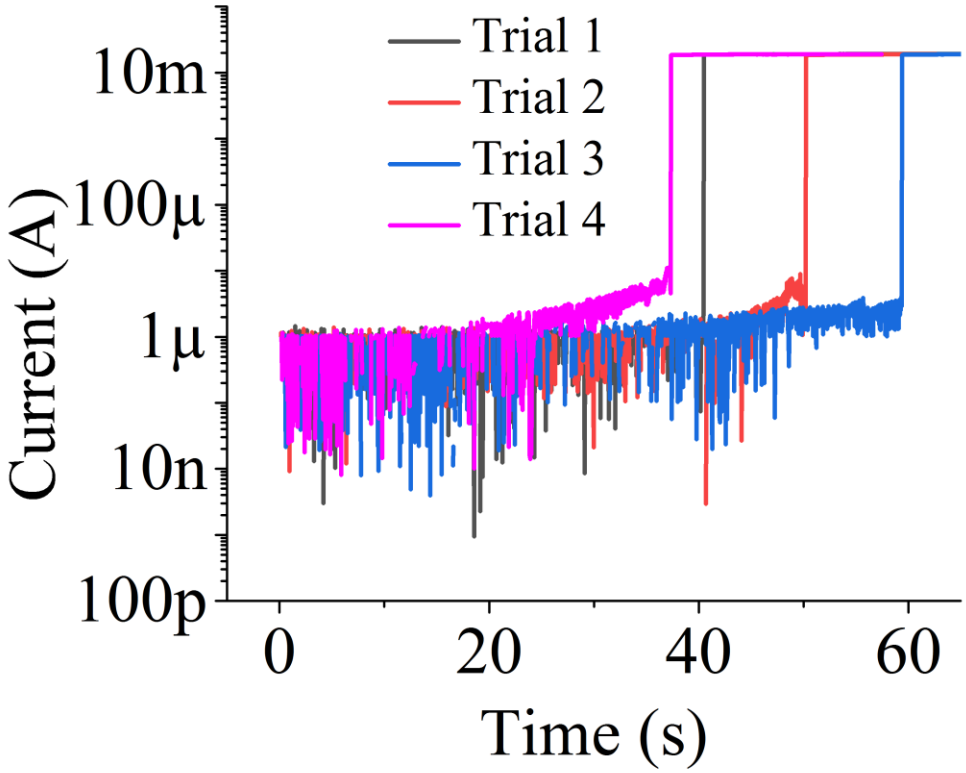


FIG. S12. Concentration = 25 mg/ml

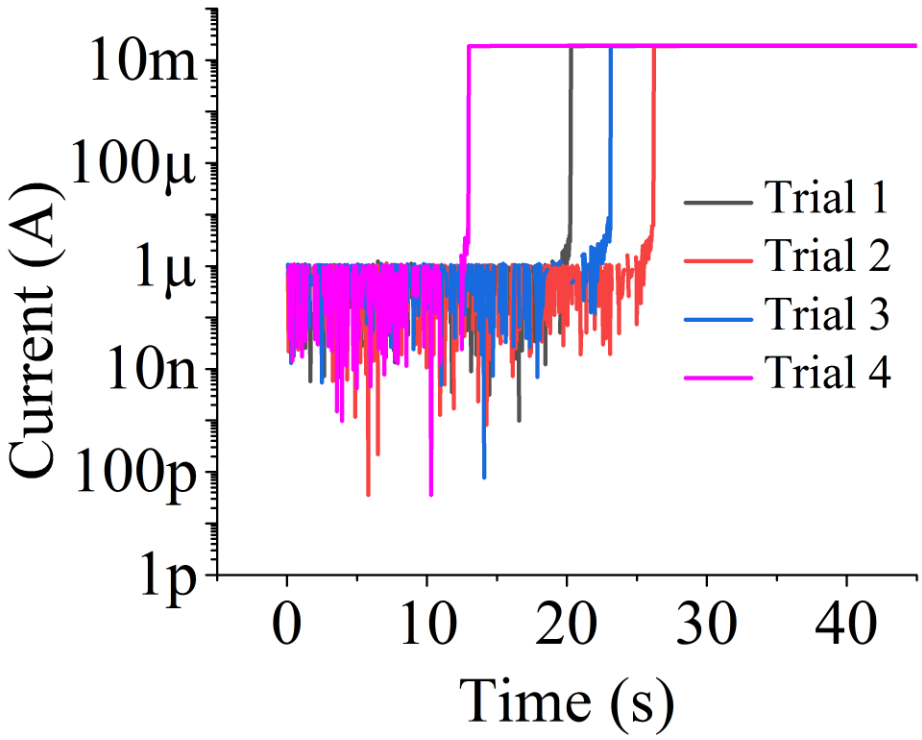


FIG. S13. Concentration = 50 mg/ml

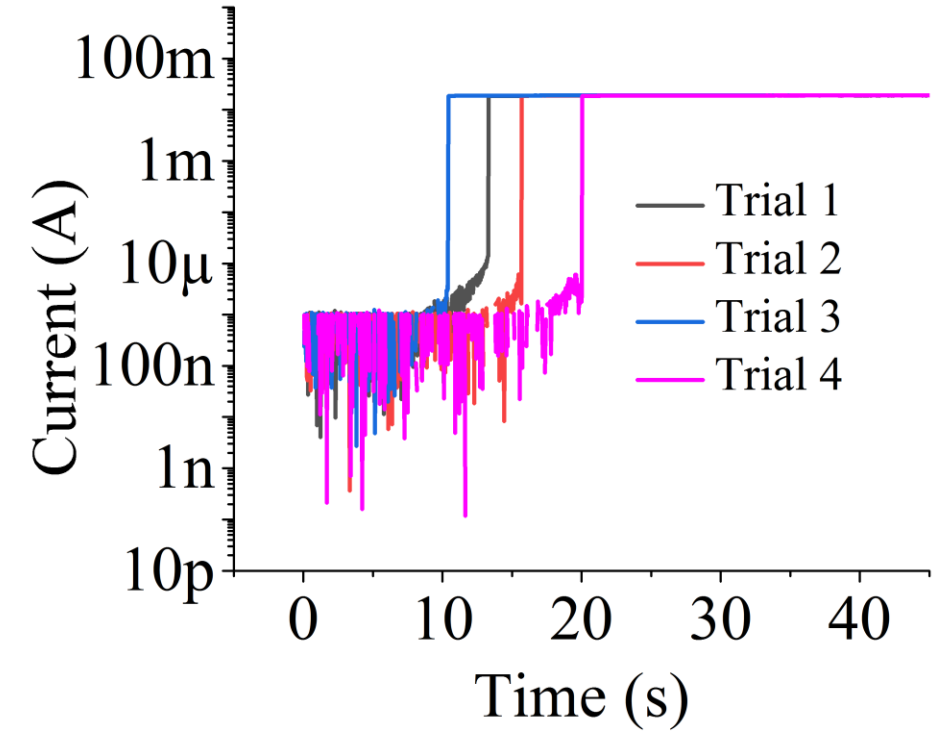


FIG. S14. Concentration = 75 mg/ml

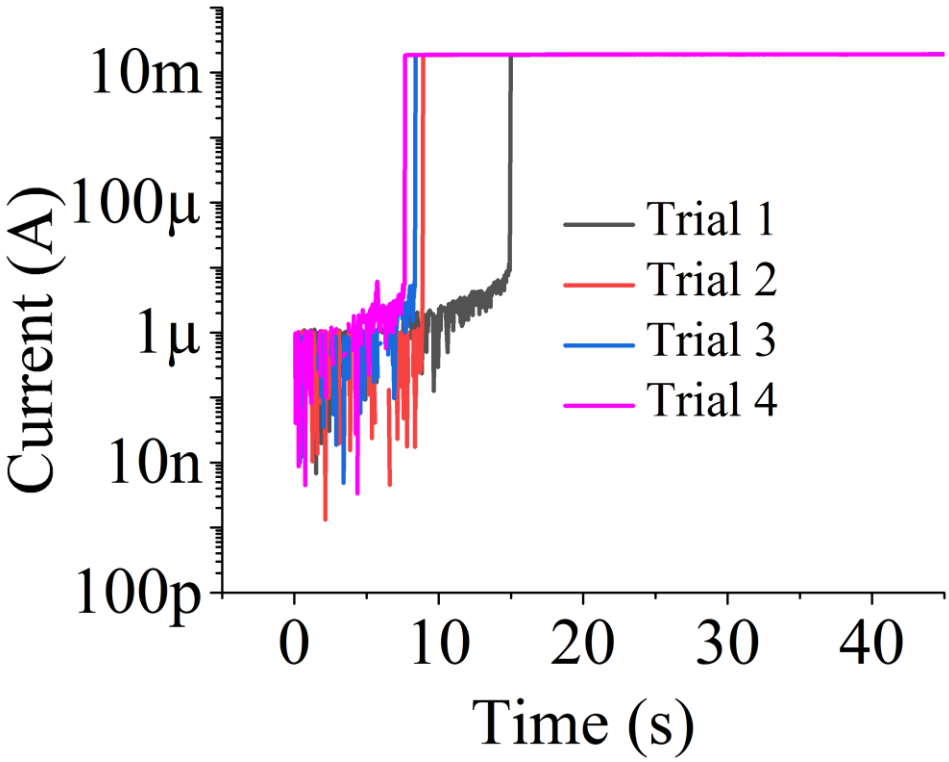


FIG. S15. Concentration = 100 mg/ml

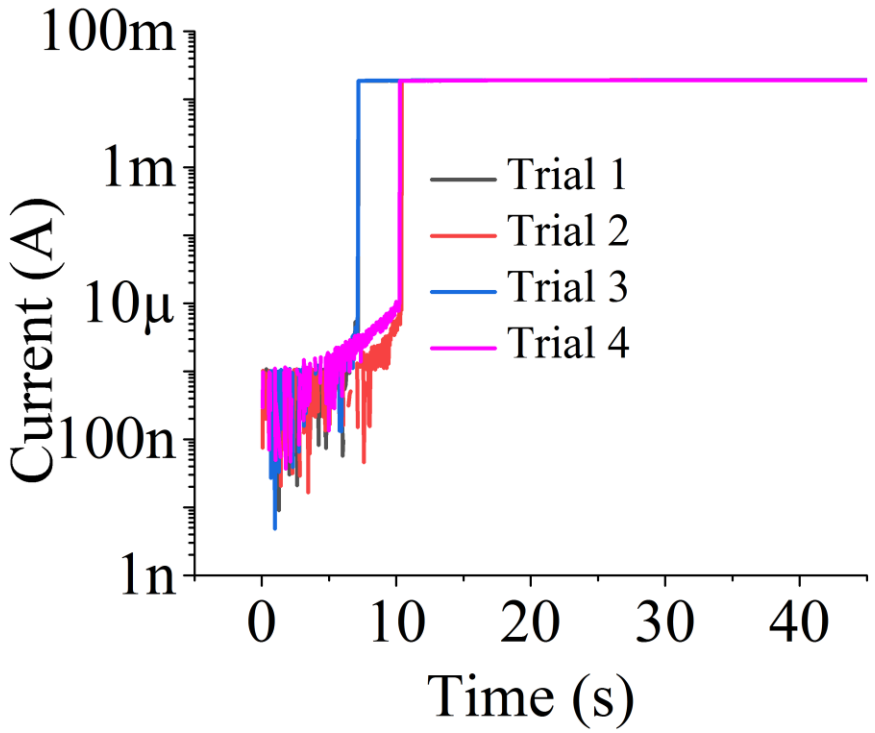


FIG. S16. Concentration = 125 mg/ml

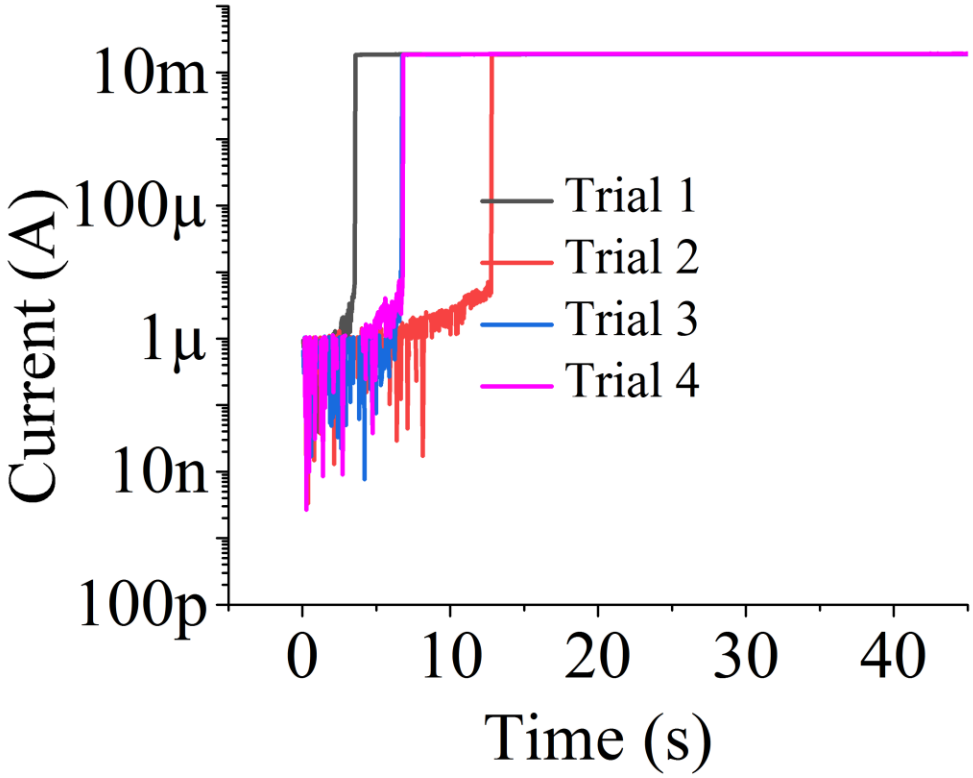


FIG. S17. Concentration = 175 mg/ml

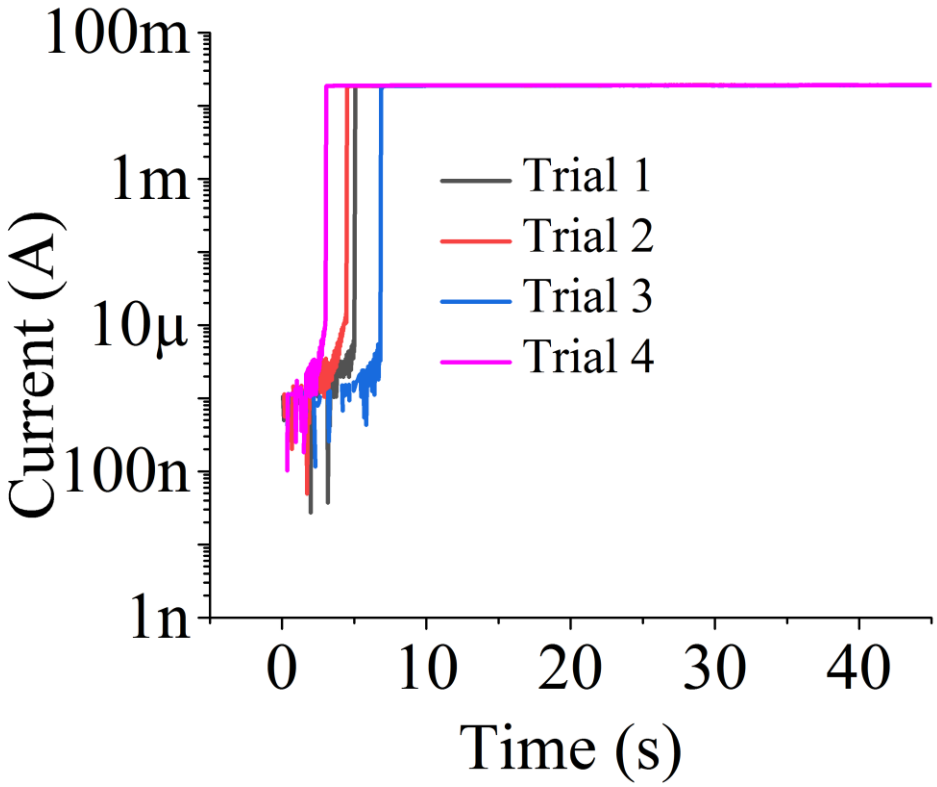


FIG. S18. Concentration = 200 mg/ml

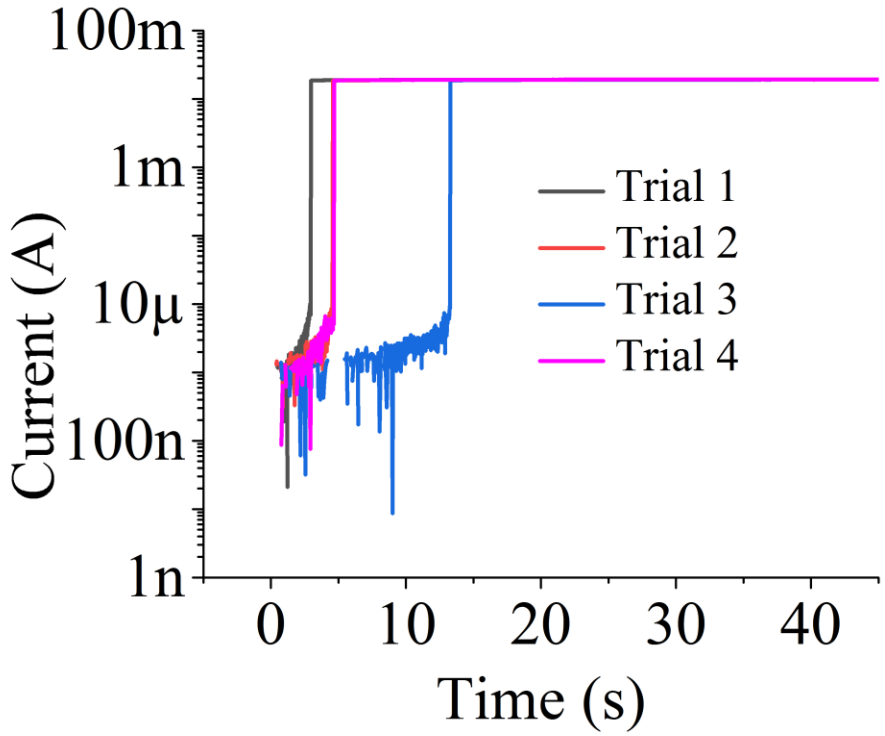


FIG. S19. Concentration = 250 mg/ml

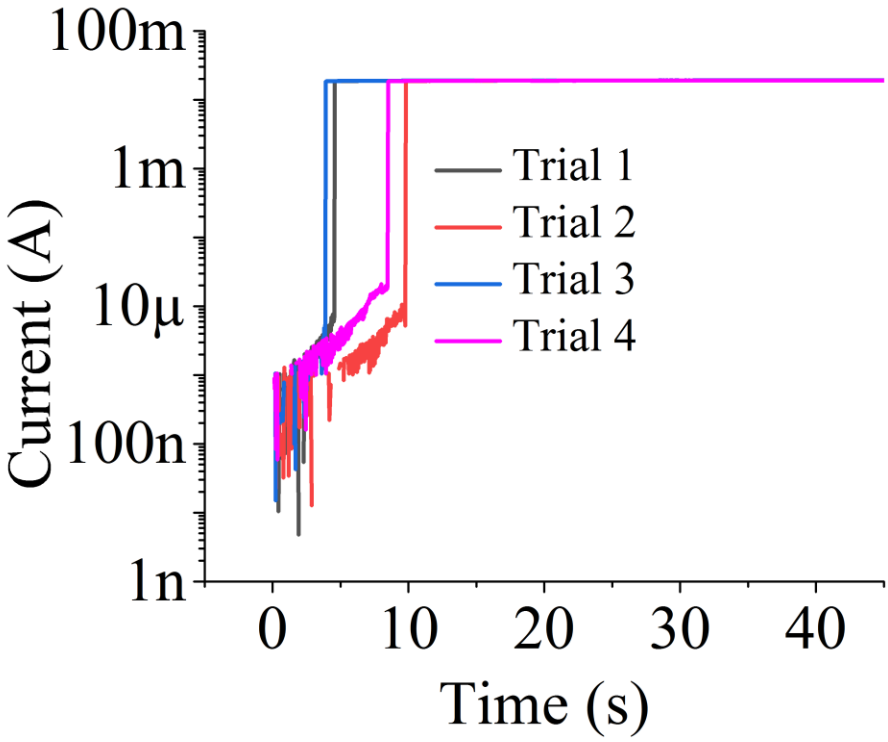


FIG. S20. Concentration = 300 mg/ml

C. 50 degree Celsius

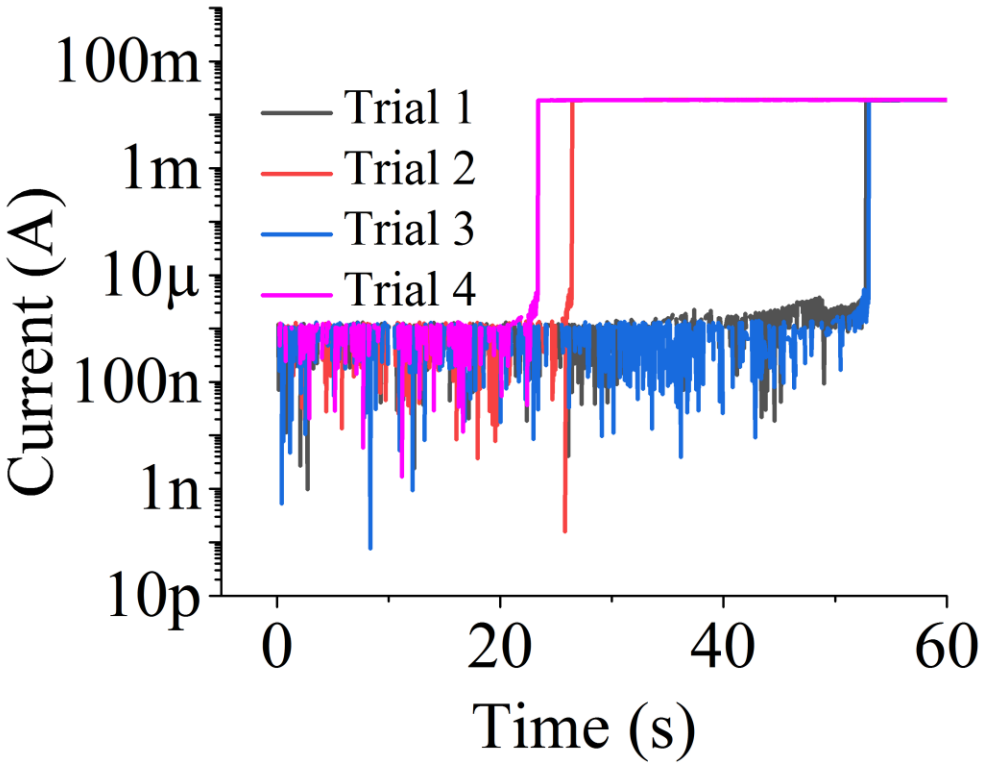


FIG. S21. Concentration = 25 mg/ml

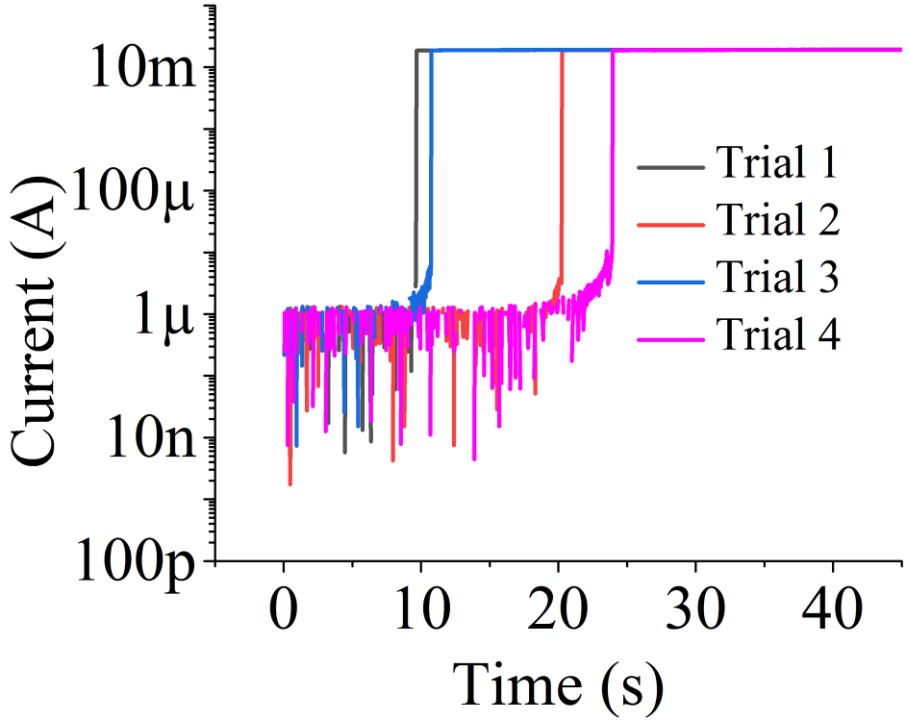


FIG. S22. Concentration = 50 mg/ml

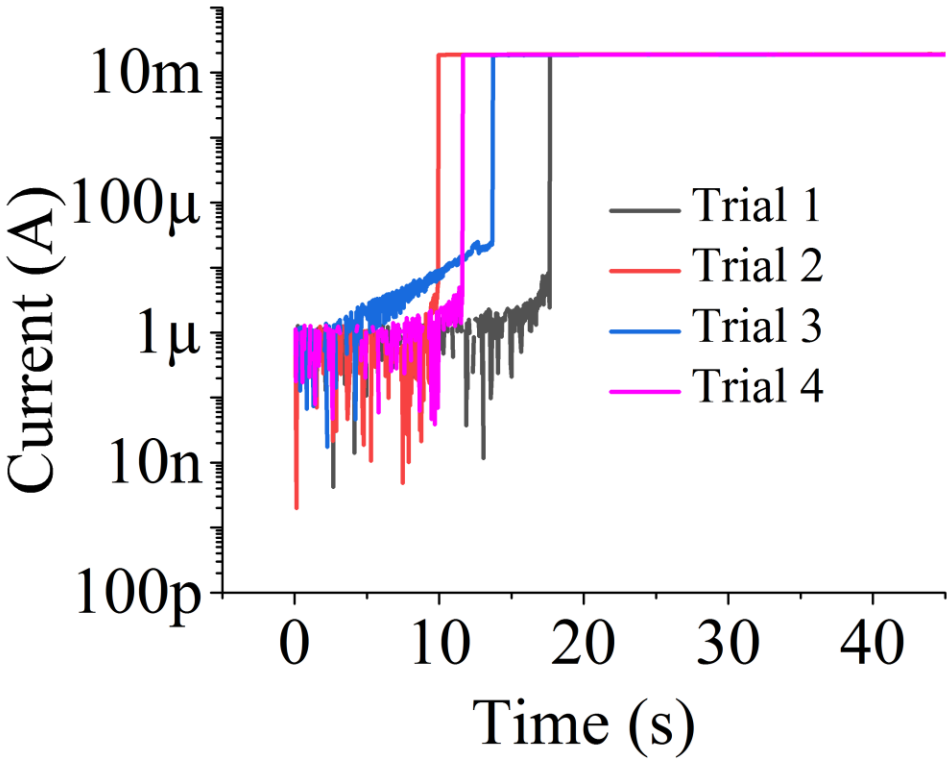


FIG. S23. Concentration = 75 mg/ml

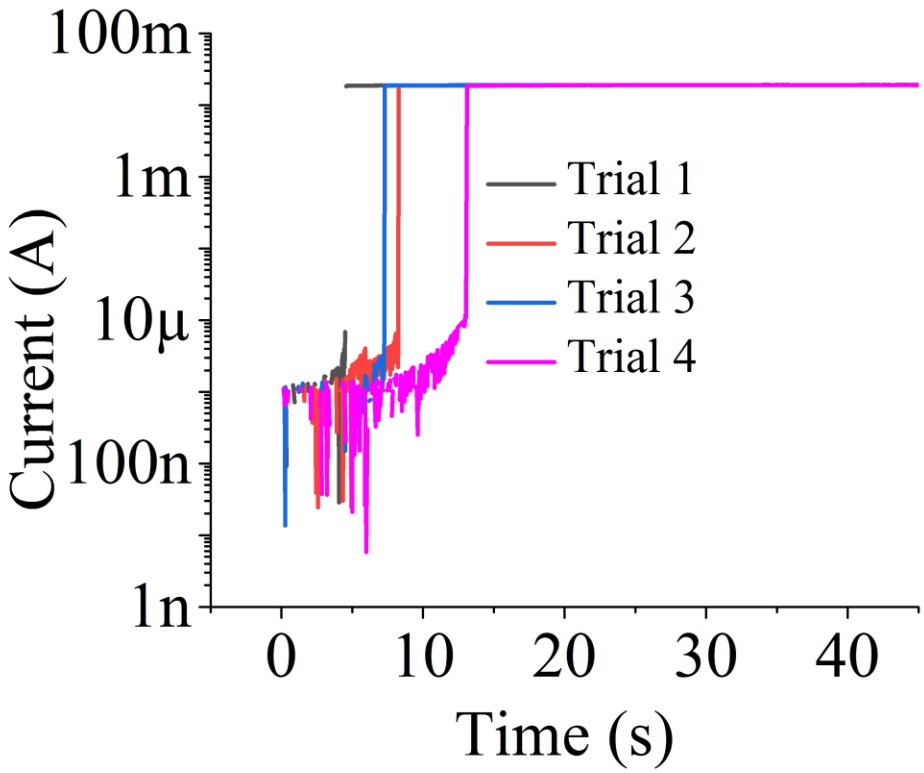


FIG. S24. Concentration = 100 mg/ml

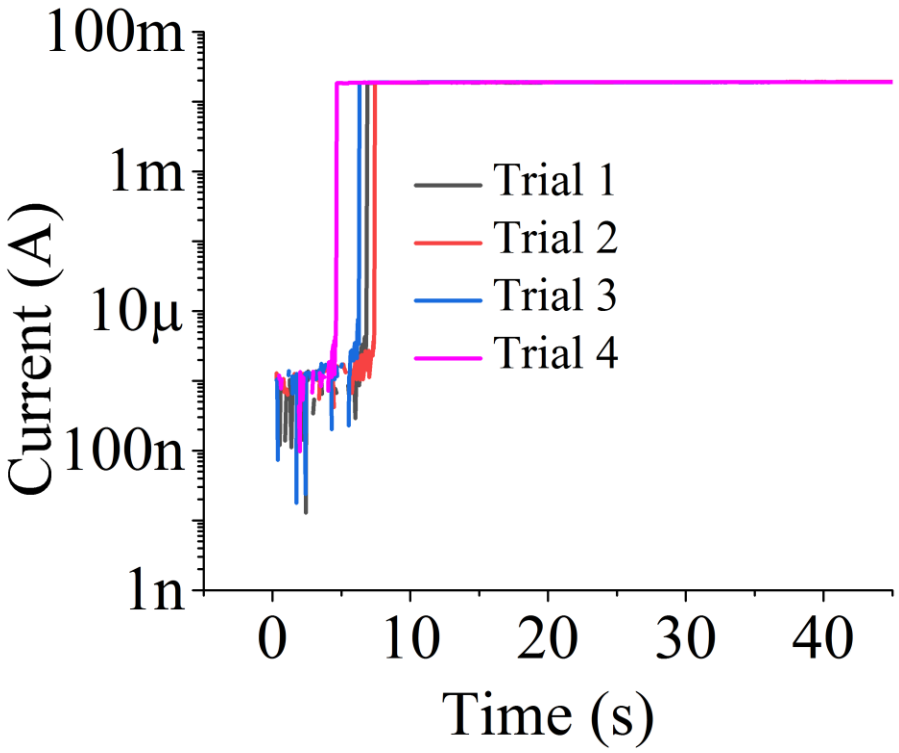


FIG. S25. Concentration = 125 mg/ml

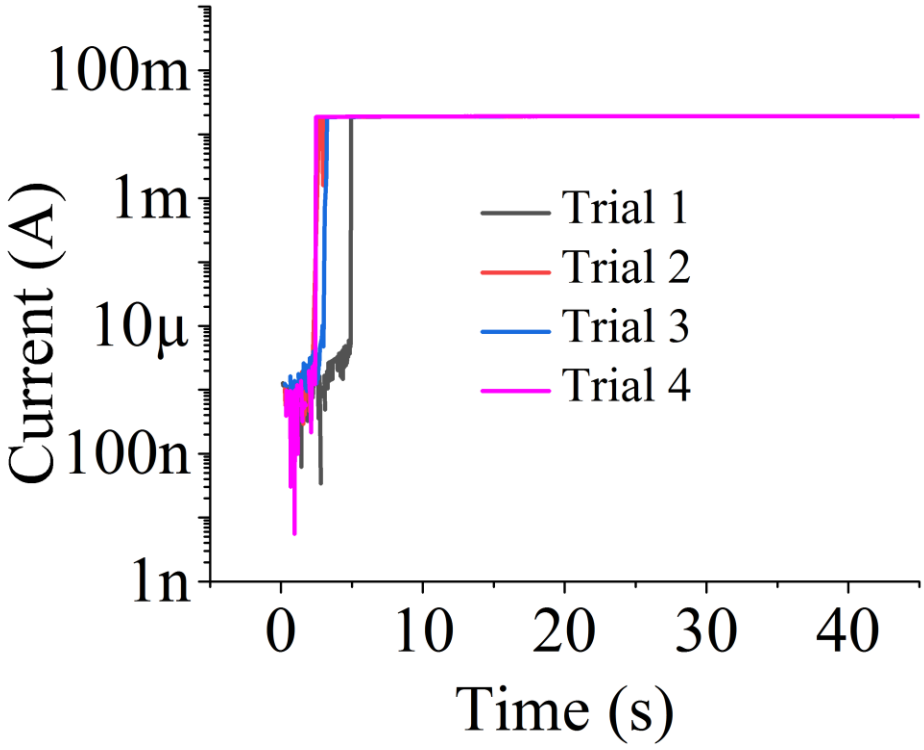


FIG. S26. Concentration = 175 mg/ml

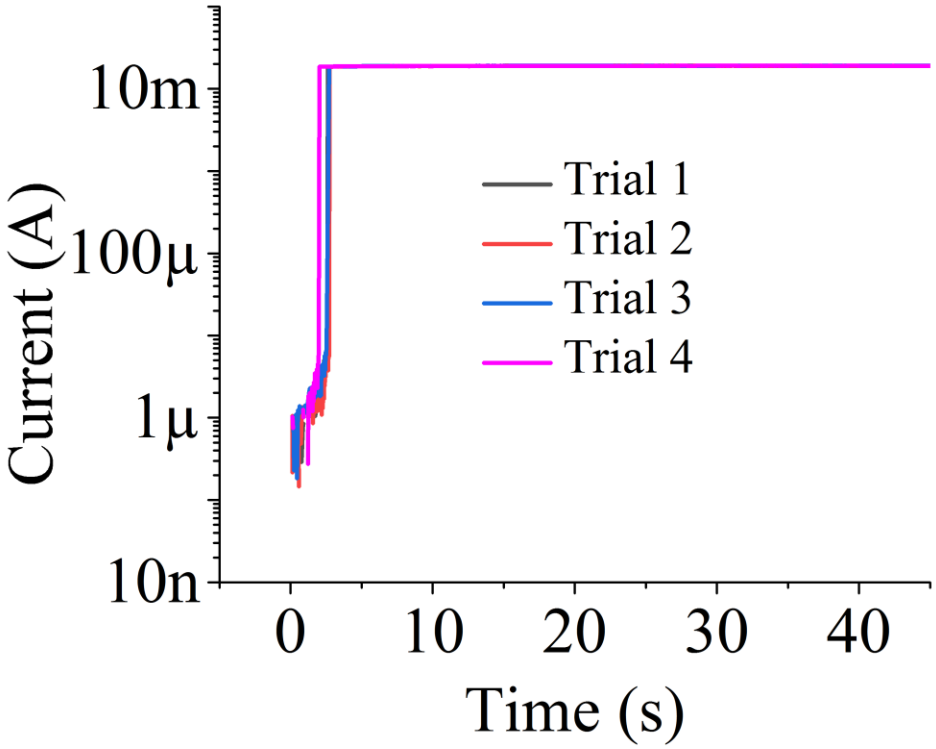


FIG. S27. Concentration = 200 mg/ml

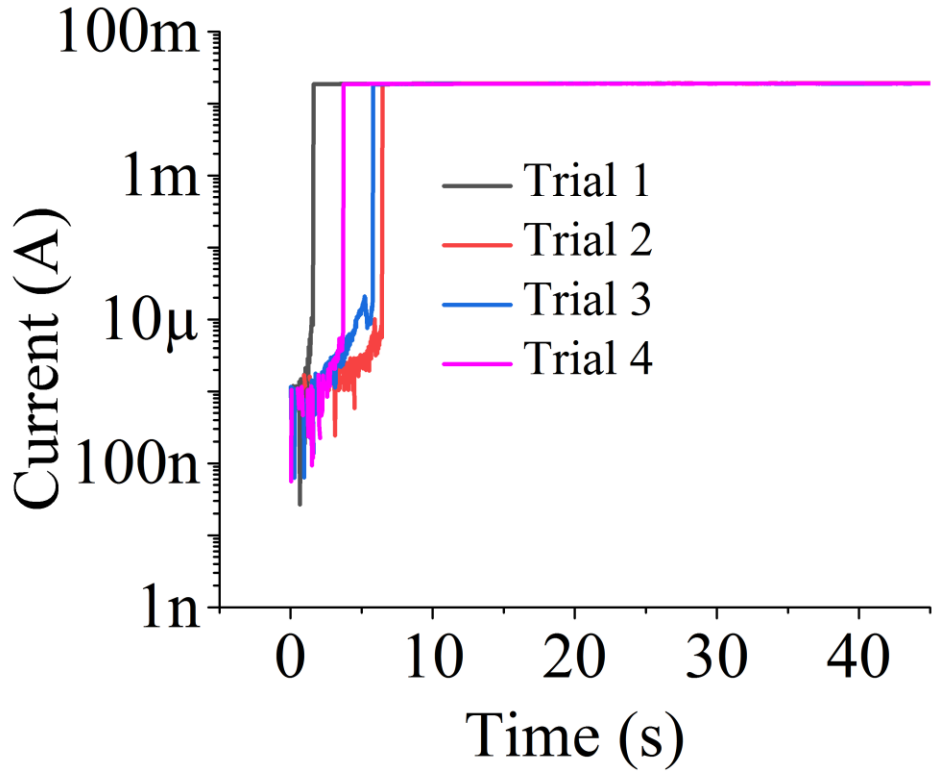


FIG. S28. Concentration = 250 mg/ml

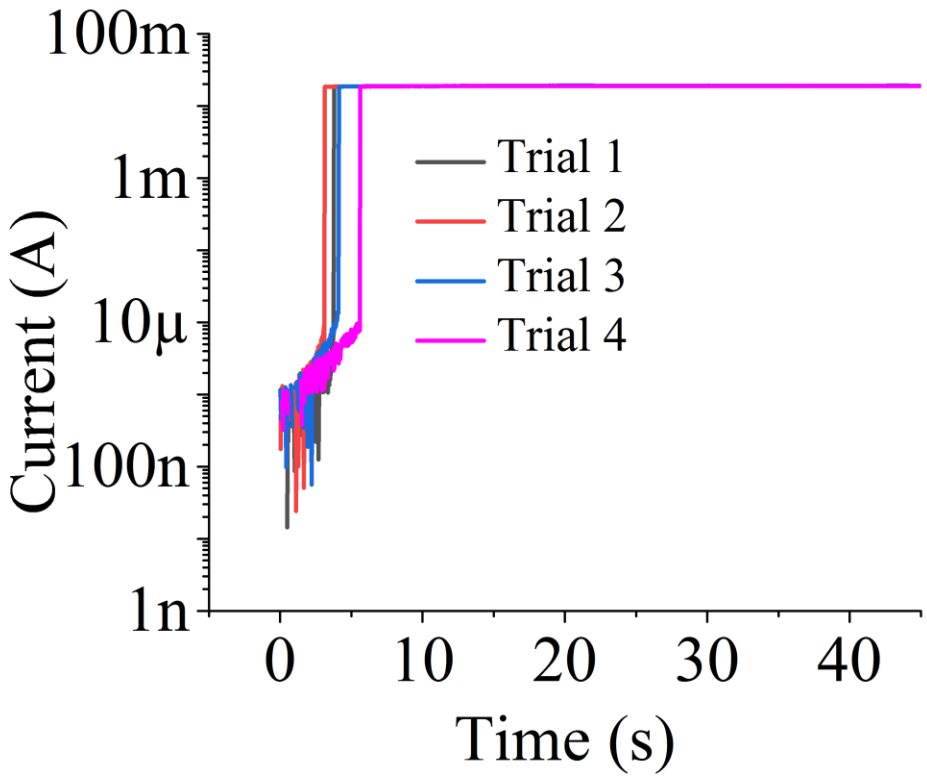


FIG. S29. Concentration = 300 mg/ml

D. 60 degree Celsius

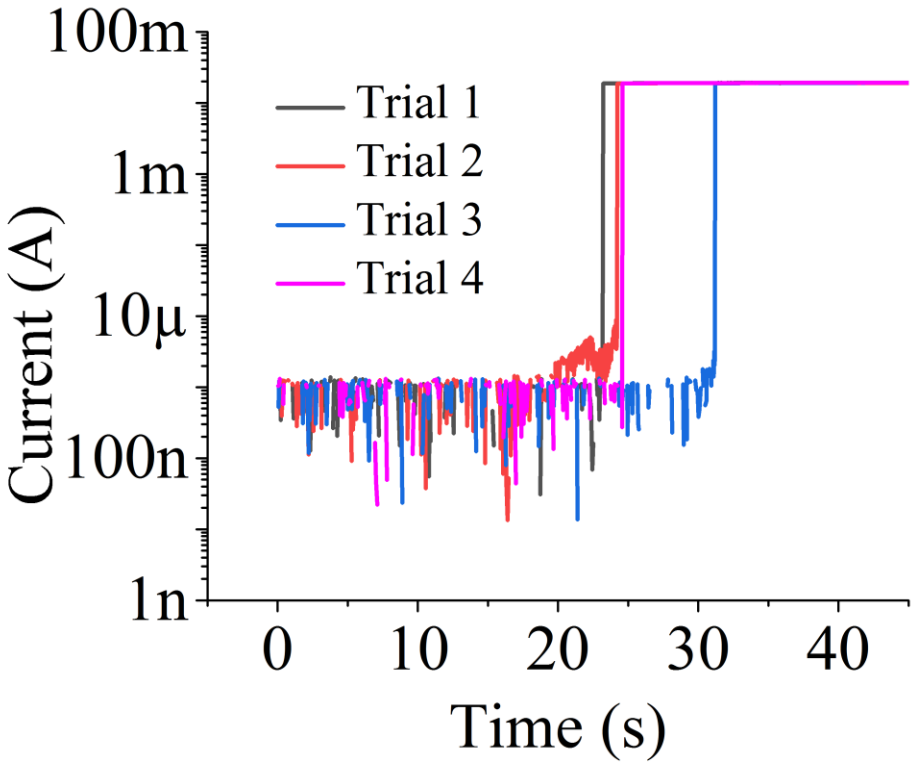


FIG. S30. Concentration = 25 mg/ml

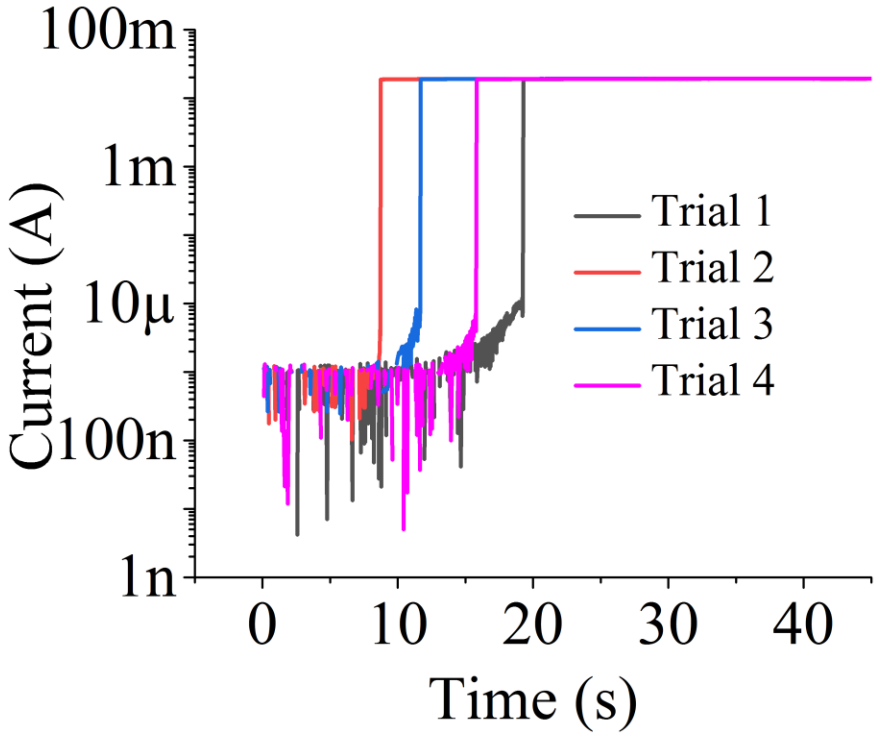


FIG. S31. Concentration = 50 mg/ml

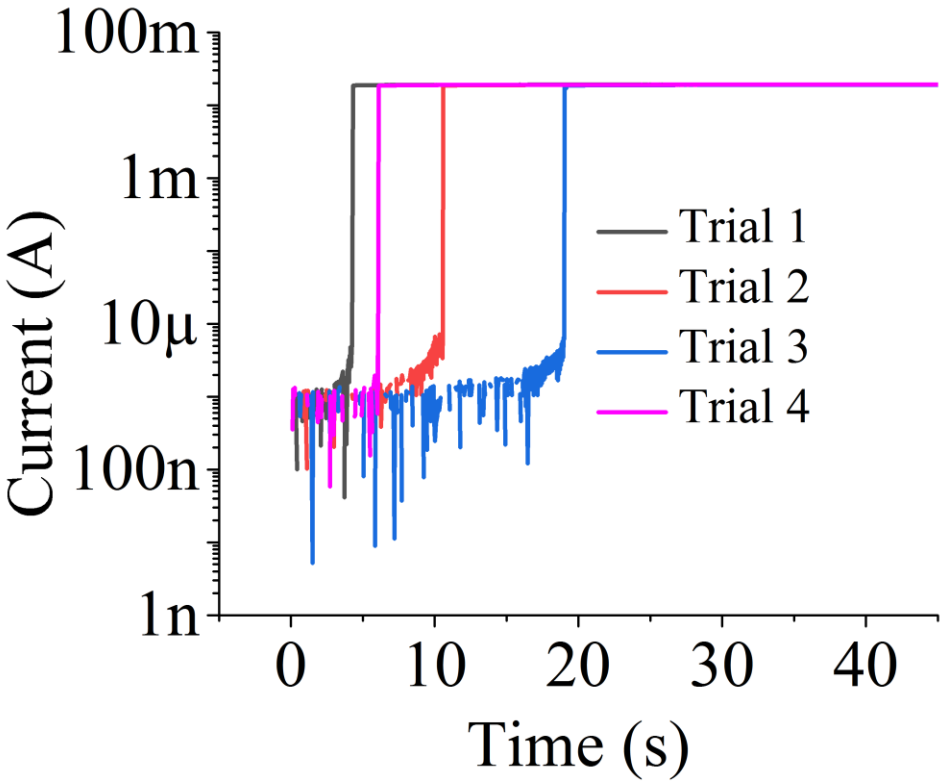


FIG. S32. Concentration = 75 mg/ml

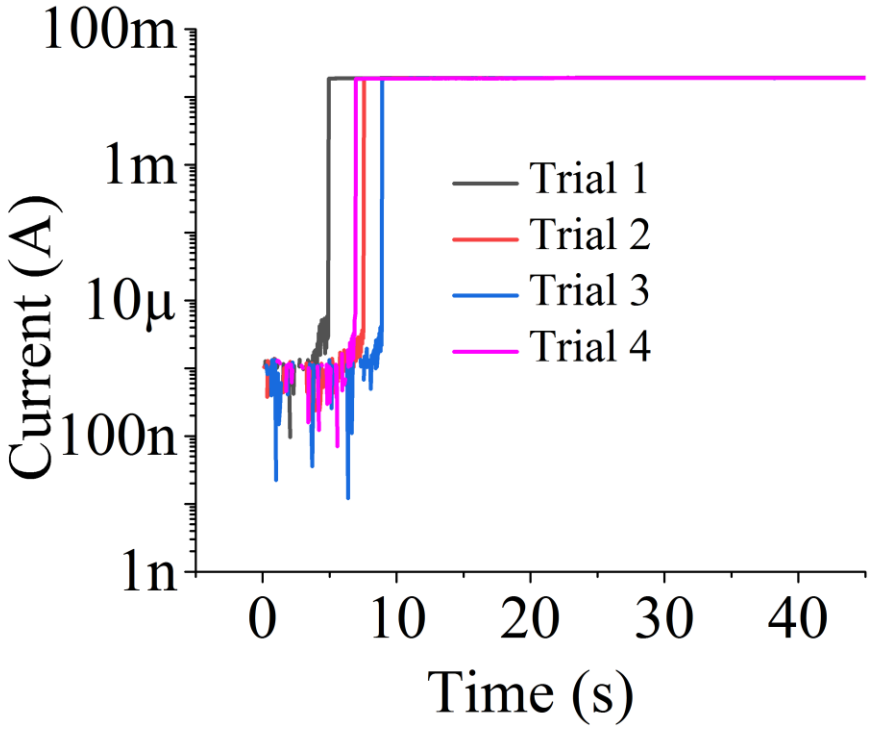


FIG. S33. Concentration = 100 mg/ml

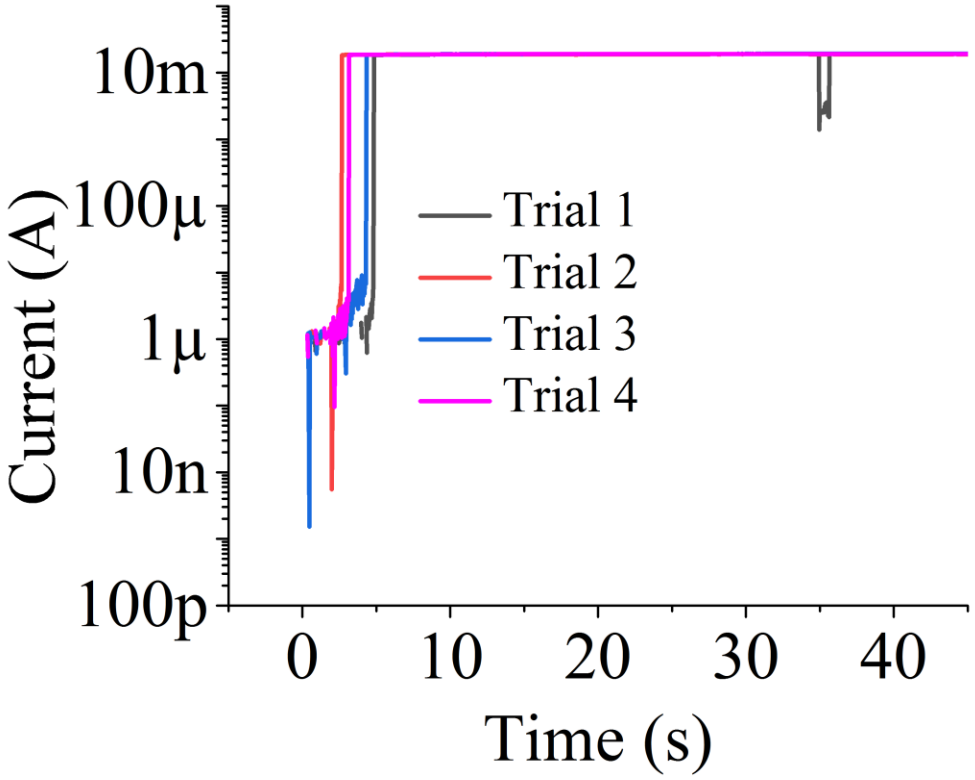


FIG. S34. Concentration = 125 mg/ml

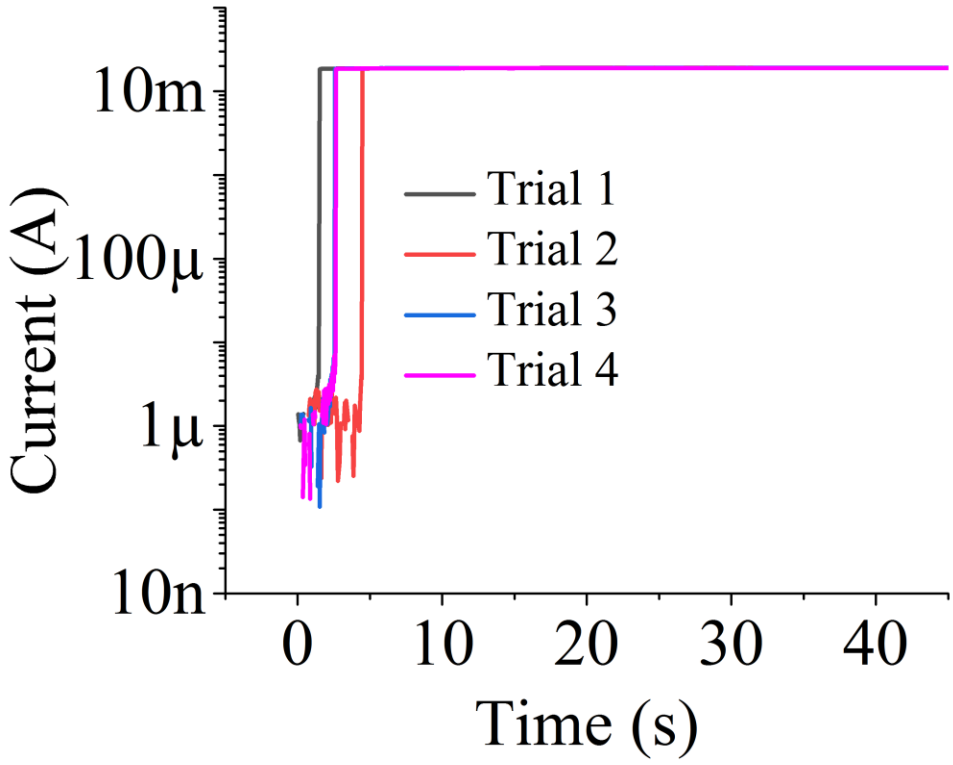


FIG. S35. Concentration = 175 mg/ml

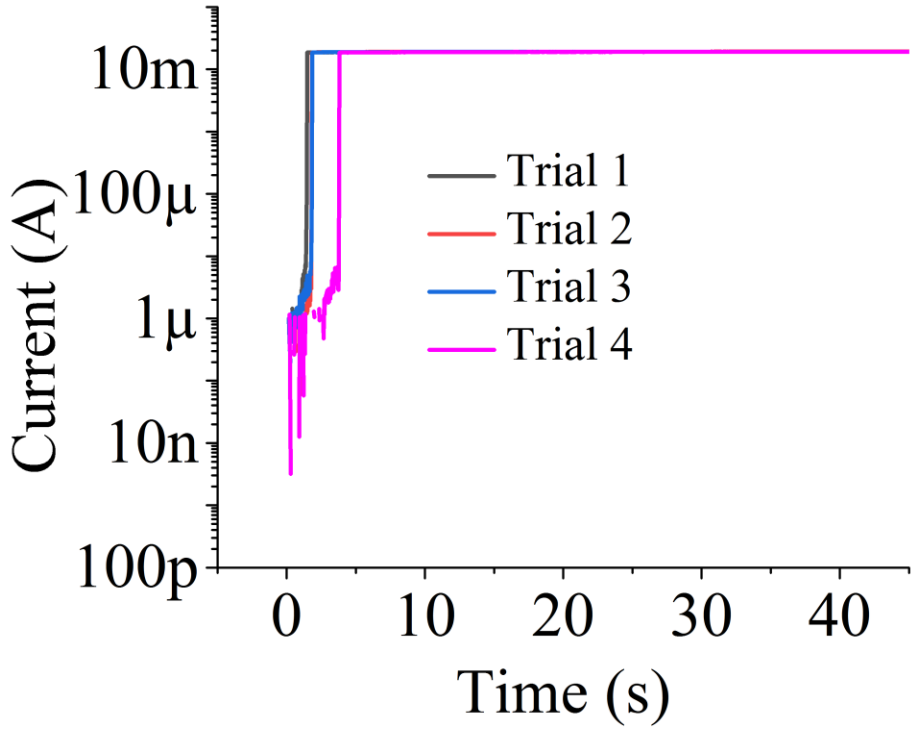


FIG. S36. Concentration = 200 mg/ml

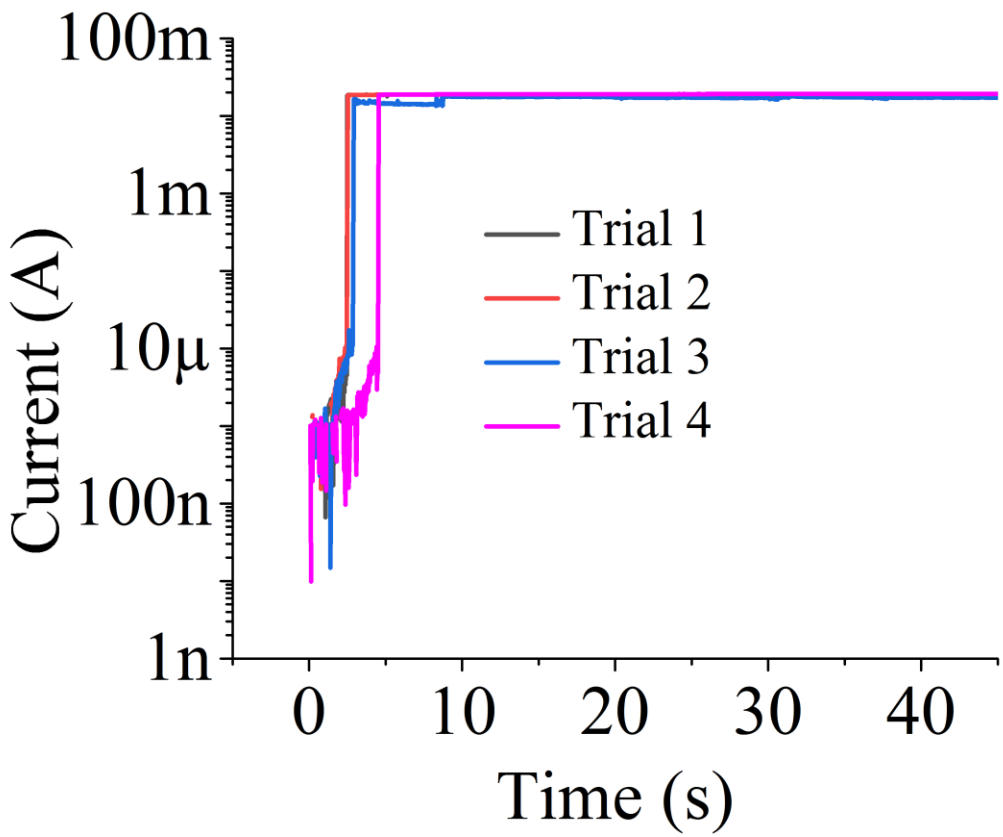


FIG. S37. Concentration = 250 mg/ml

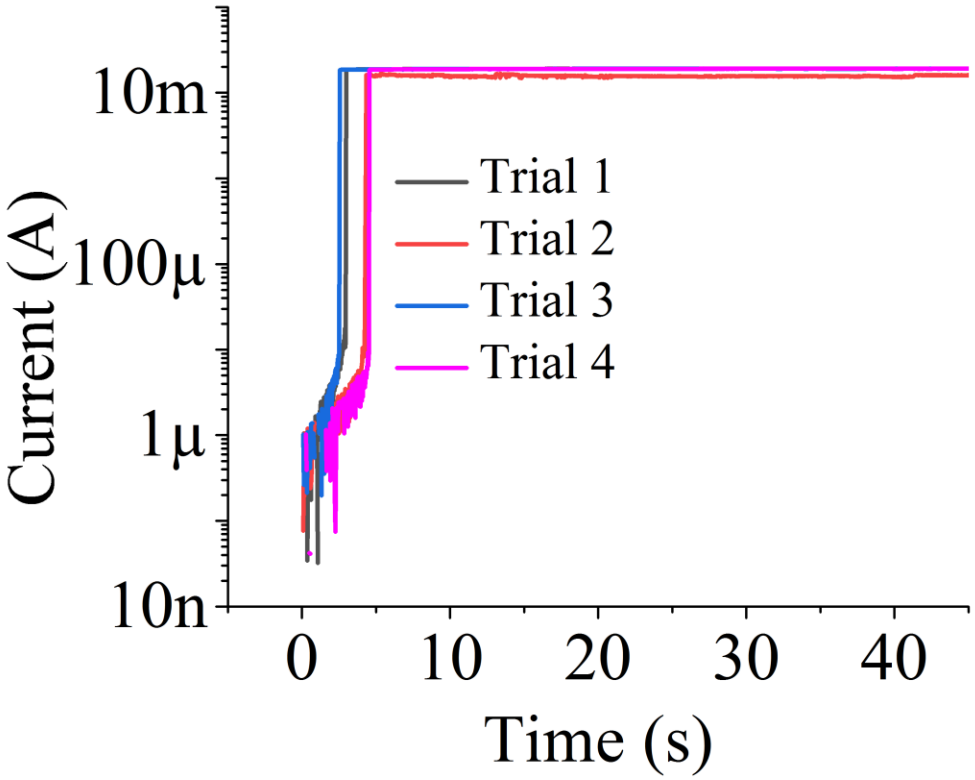


FIG. S38. Concentration = 300 mg/ml

E. 50 degree Celsius

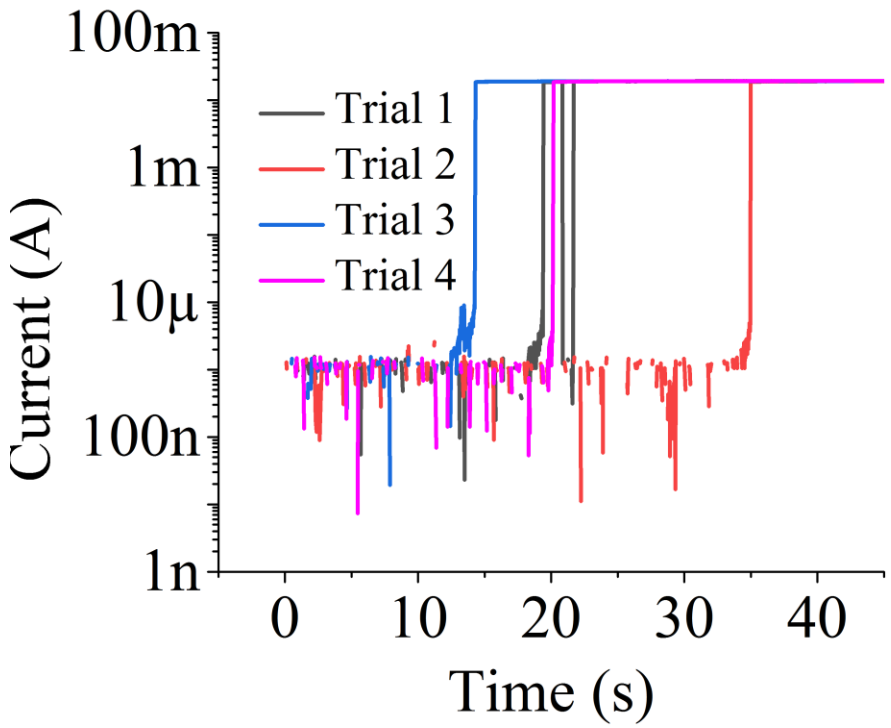


FIG. S39. Concentration = 25 mg/ml

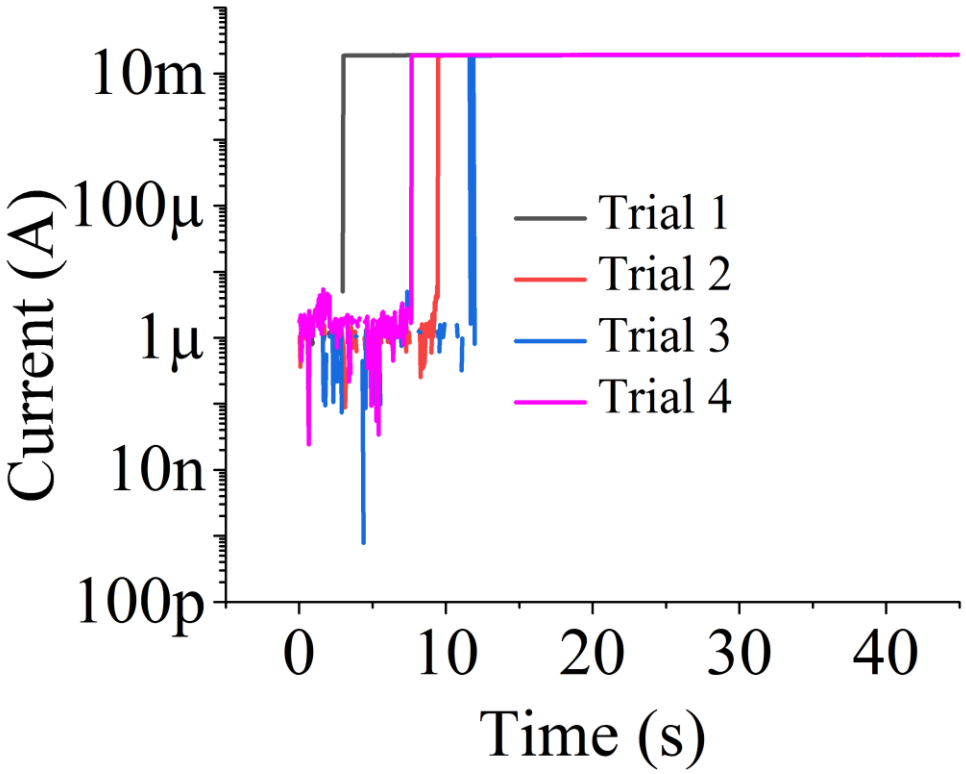


FIG. S40. Concentration = 50 mg/ml

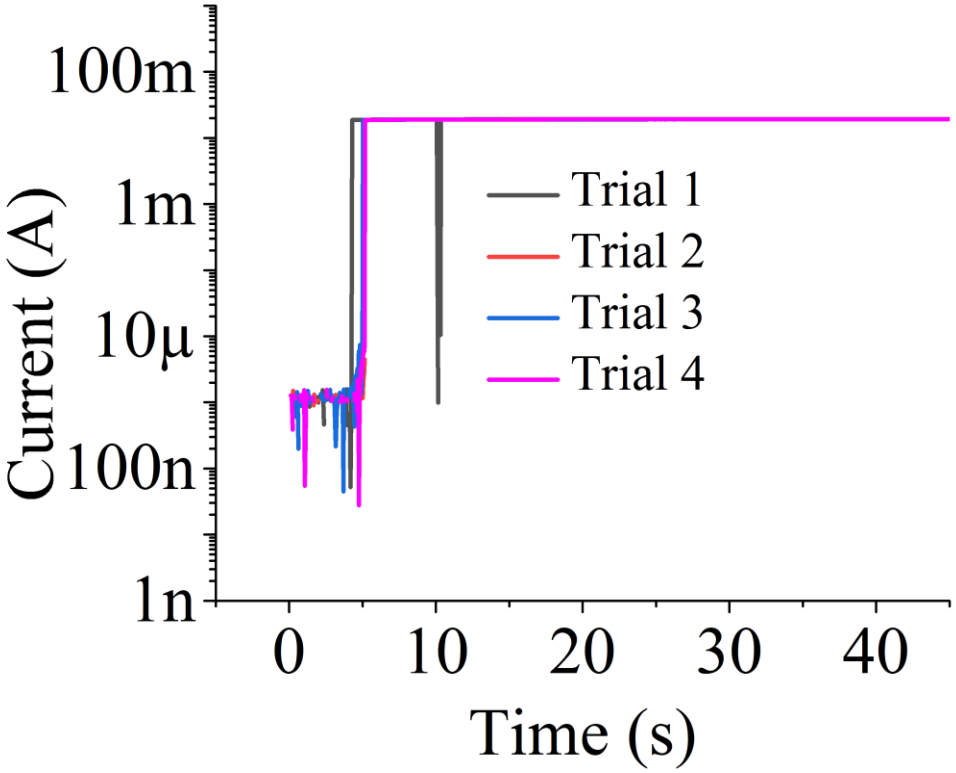


FIG. S41. Concentration = 75 mg/ml

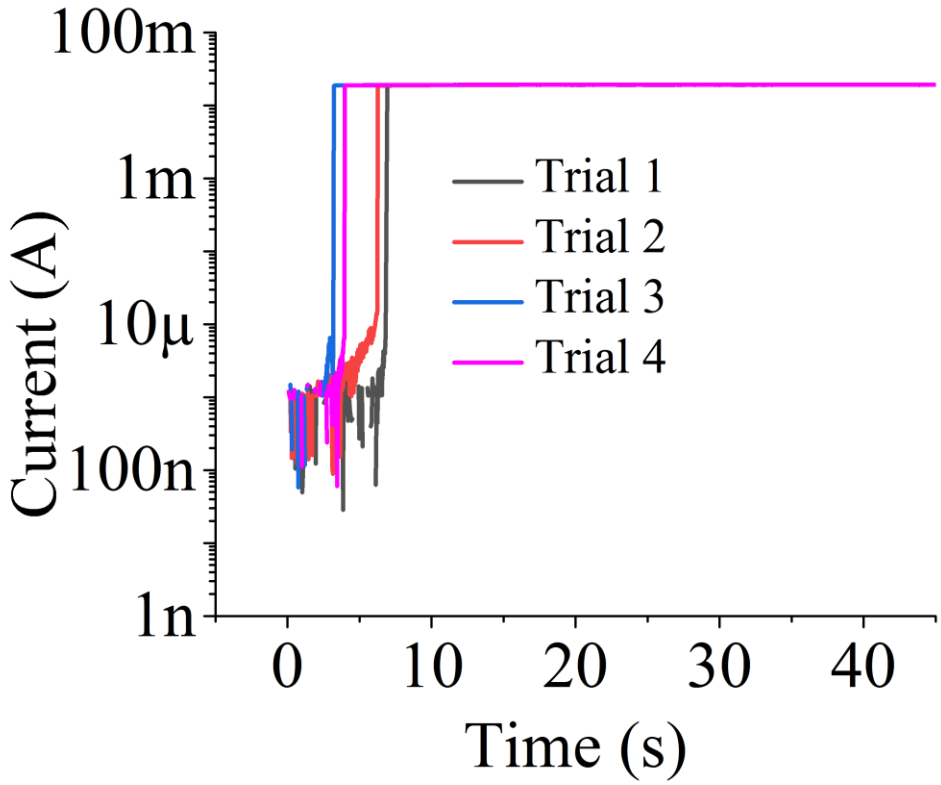


FIG. S42. Concentration = 100 mg/ml

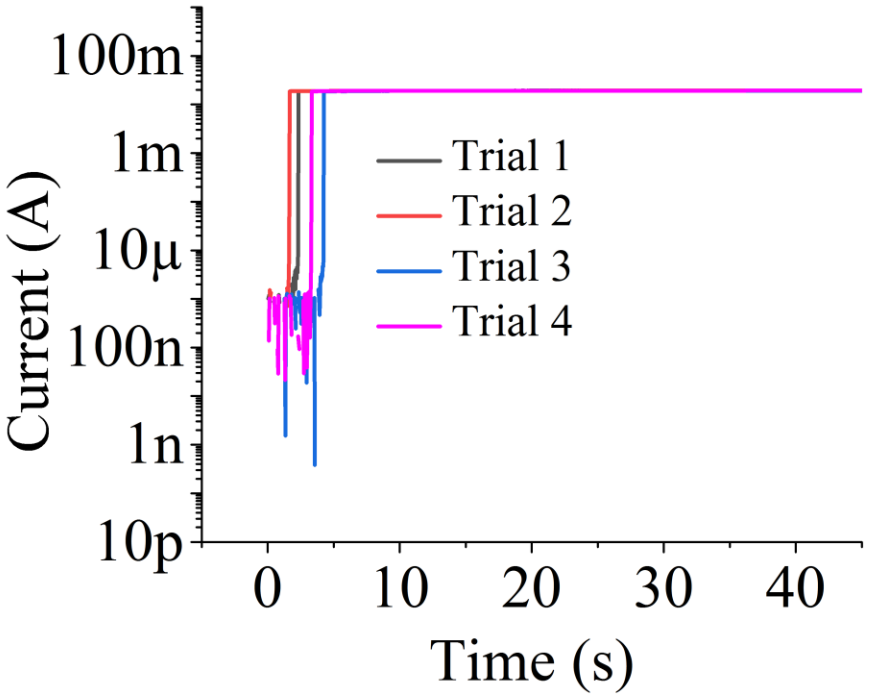


FIG. S43. Concentration = 125 mg/ml

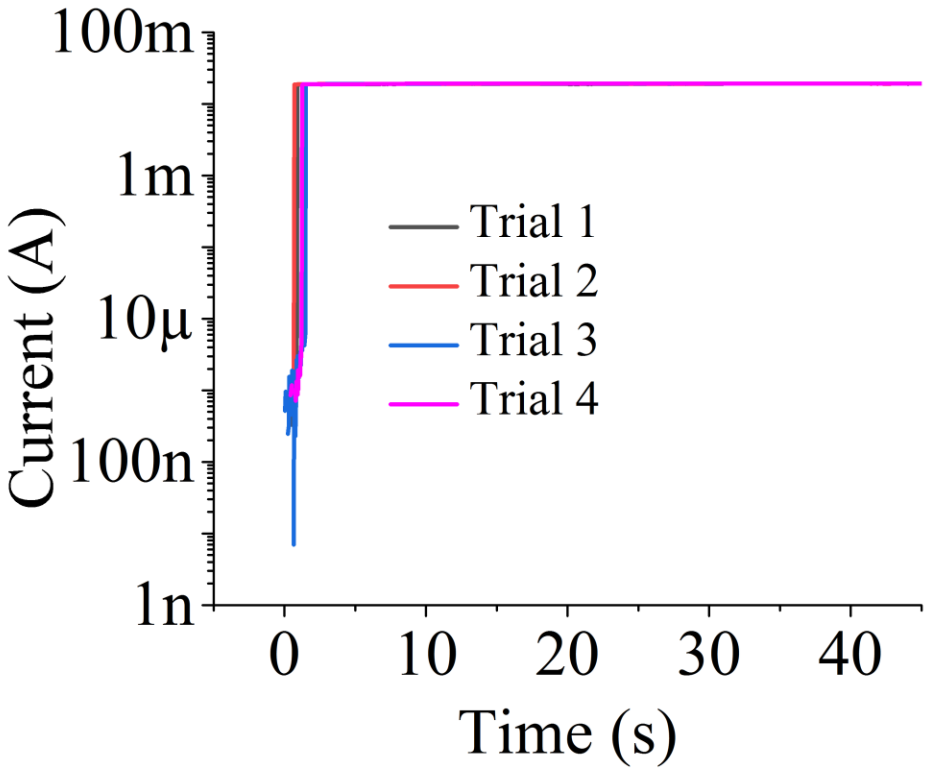


FIG. S44. Concentration = 175 mg/ml

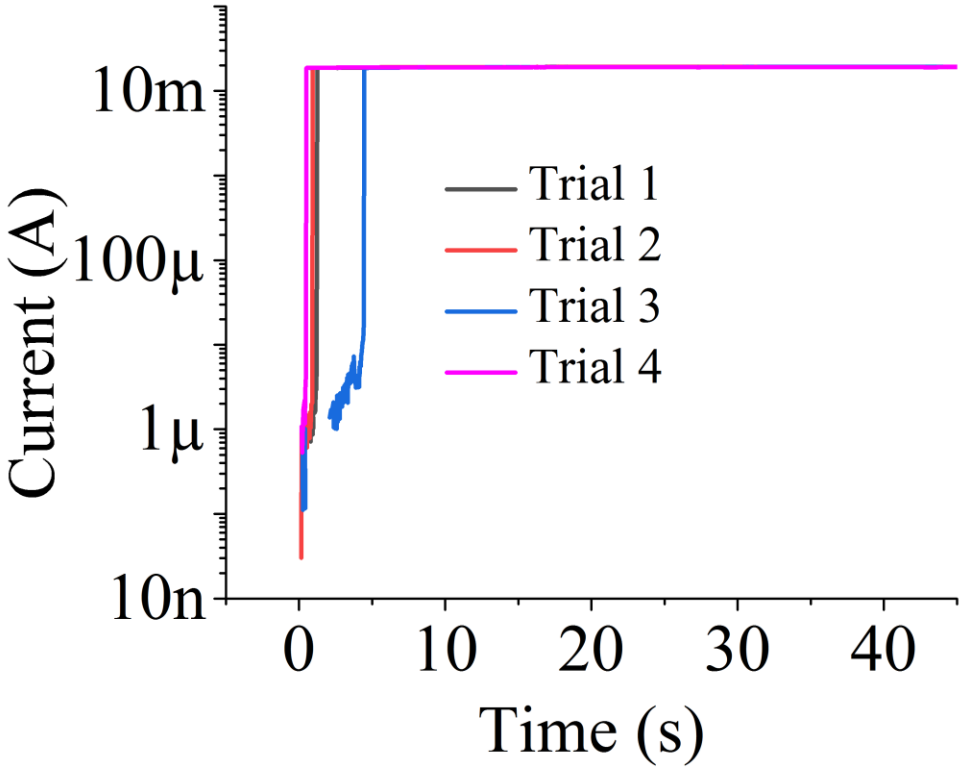


FIG. S45. Concentration = 200 mg/ml

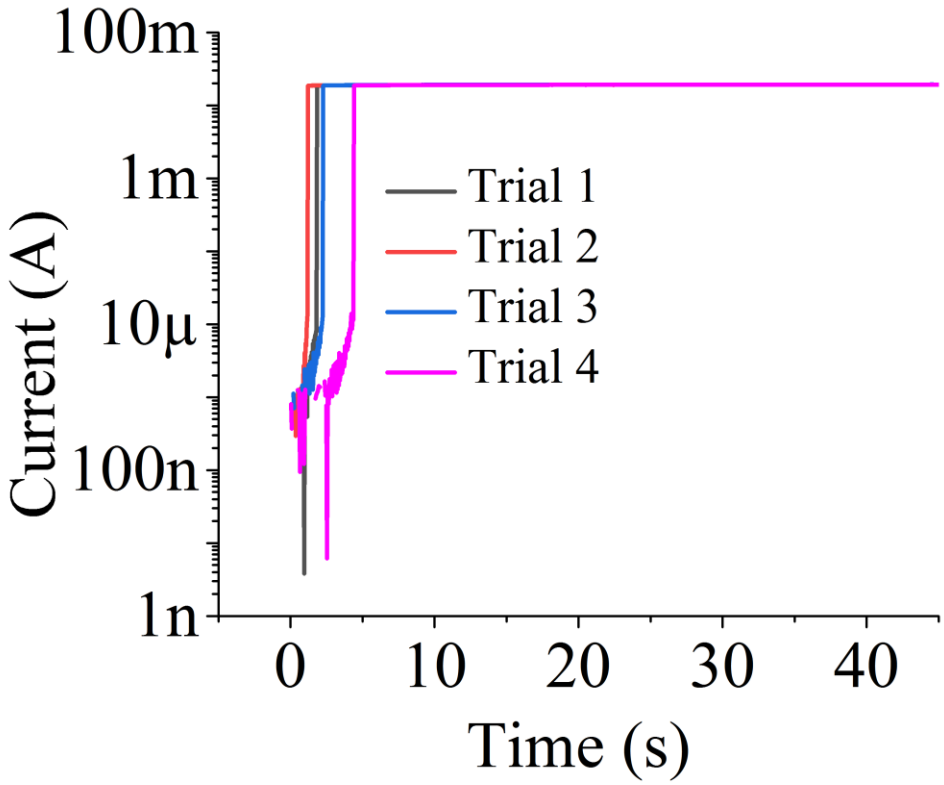


FIG. S46. Concentration = 250 mg/ml

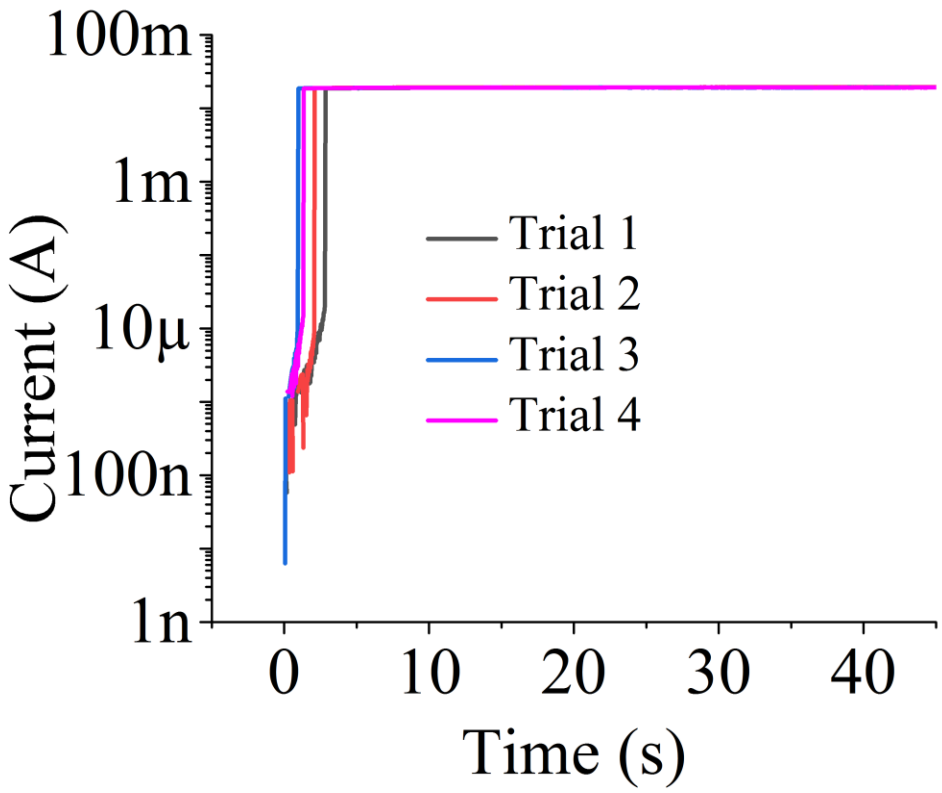


FIG. S47. Concentration = 300 mg/ml

S2. SELF-HEALING WITH GRAPHITE

A. Time Graph

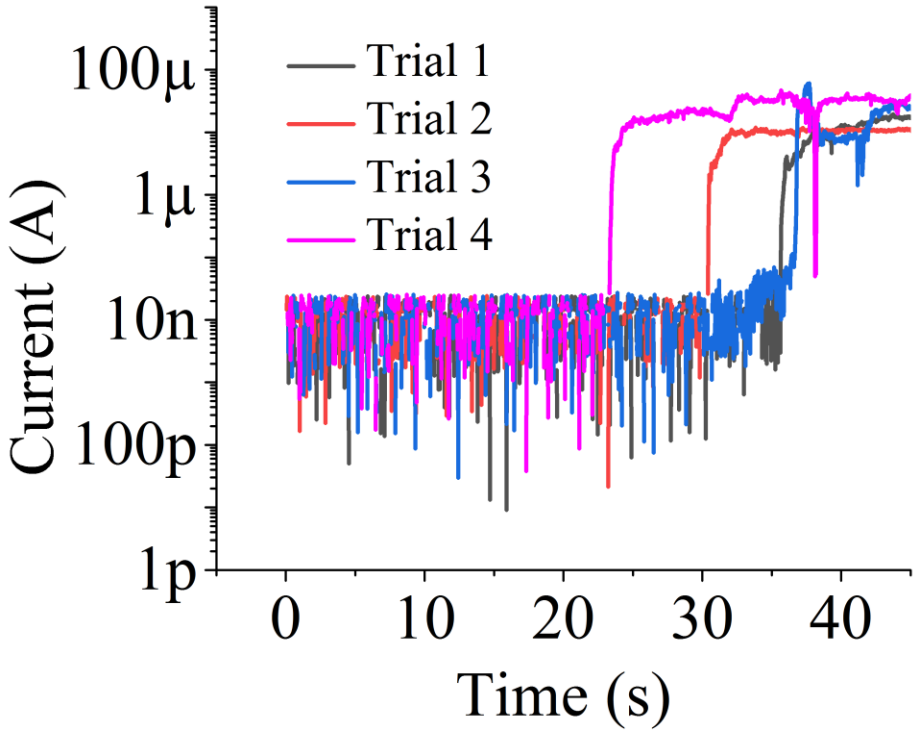


FIG. S48. Concentration = 3 mg/ml

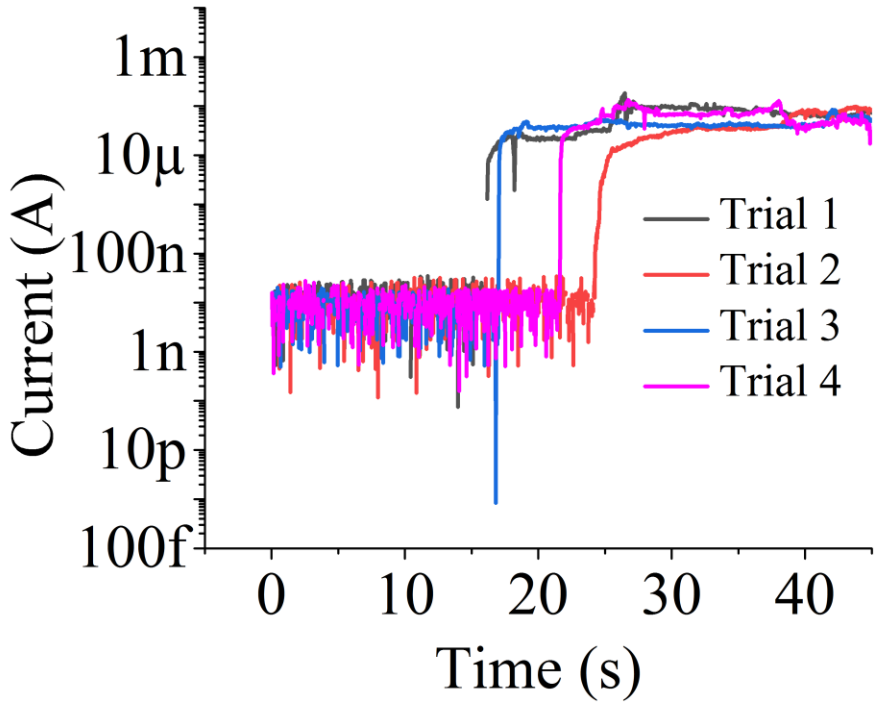


FIG. S49. Concentration = 6 mg/ml

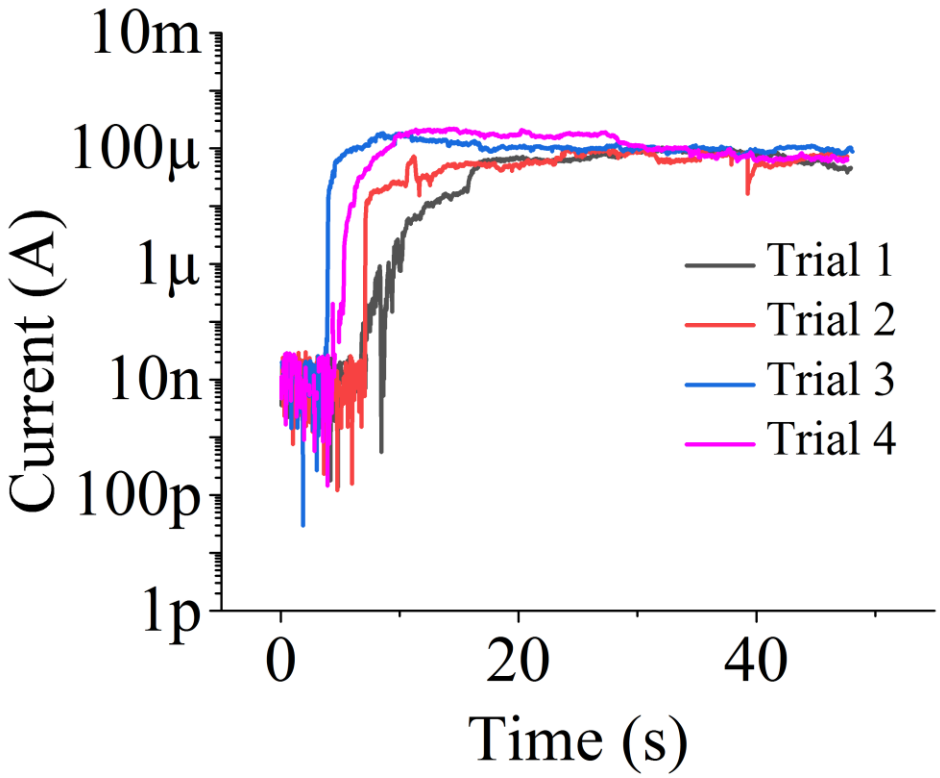


FIG. S50. Concentration = 13 mg/ml

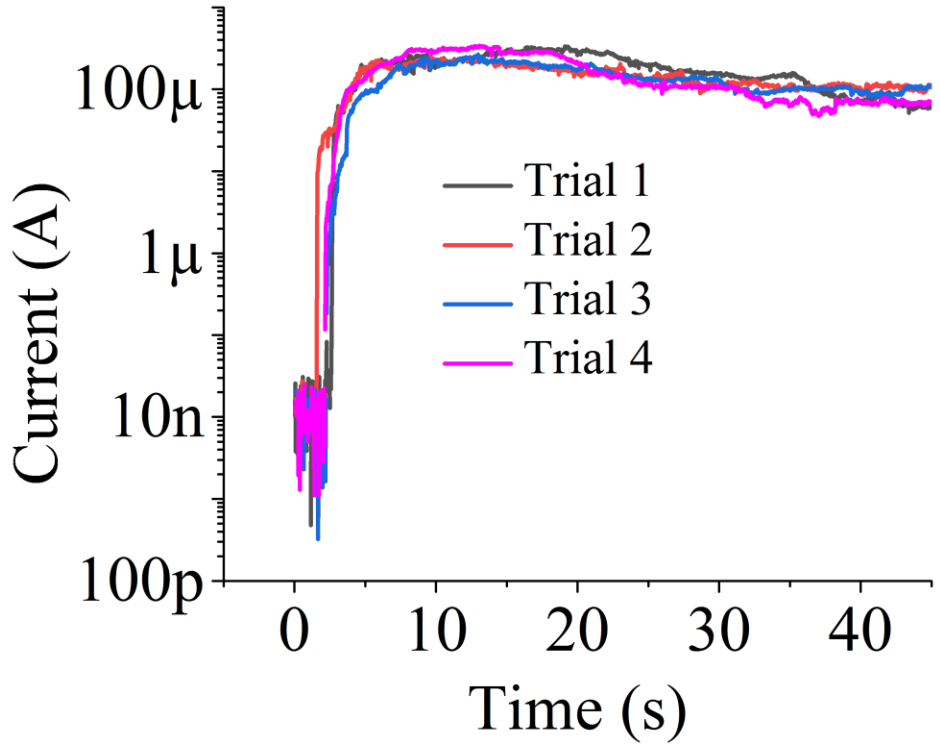


FIG. S51. Concentration = 19 mg/ml

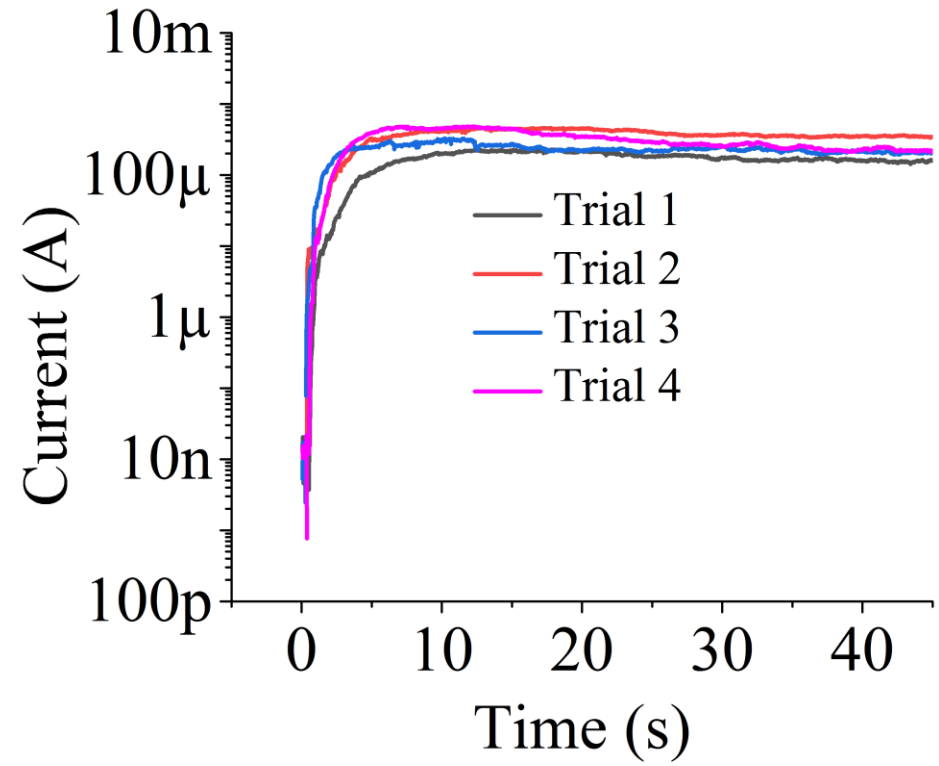


FIG. S52. Concentration = 25 mg/ml

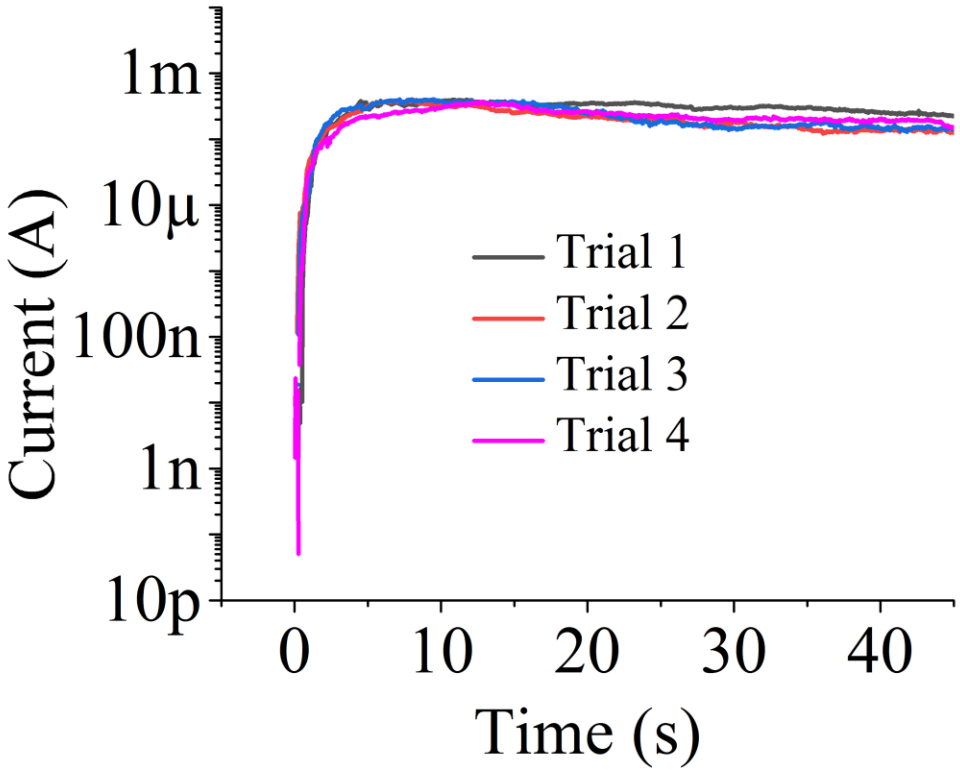


FIG. S53. Concentration = 32 mg/ml

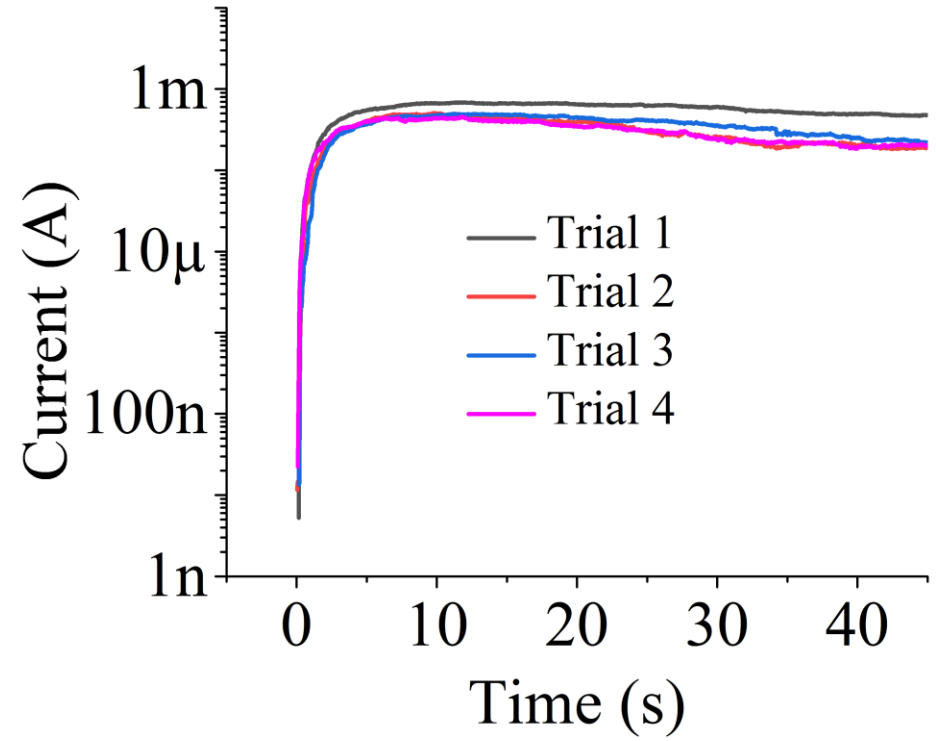


FIG. S54. Concentration = 44 mg/ml

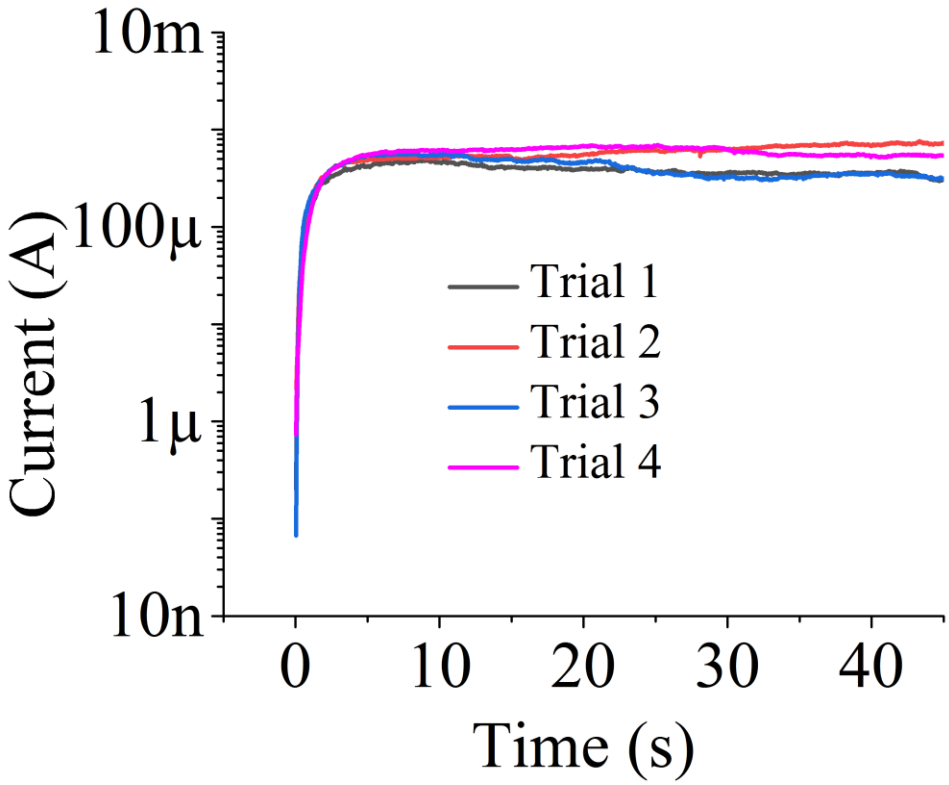


FIG. S55. Concentration = 51 mg/ml

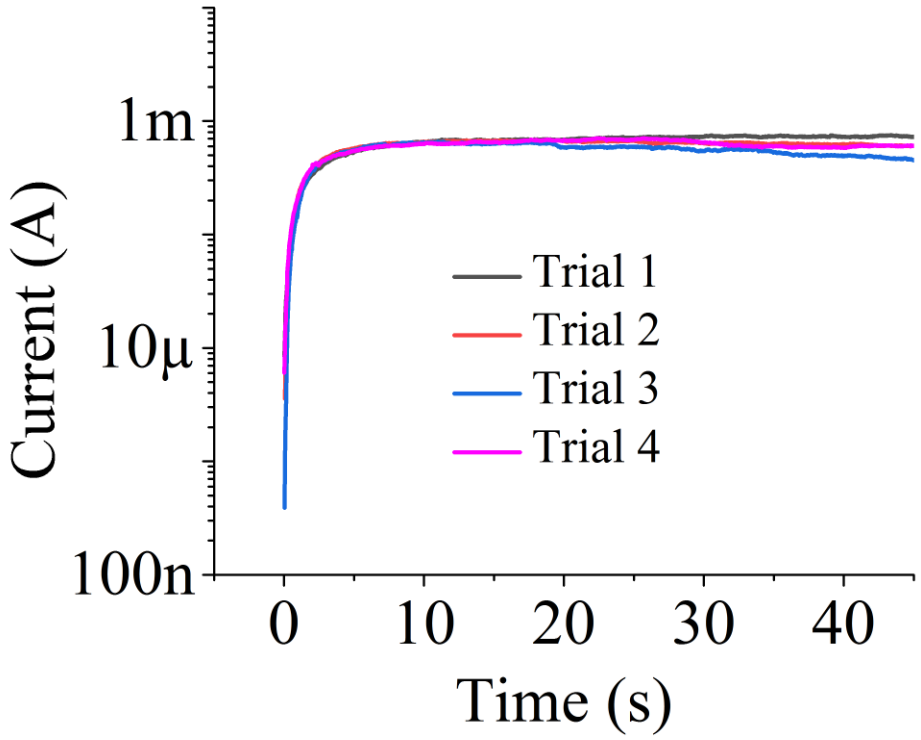


FIG. S56. Concentration = 63 mg/ml

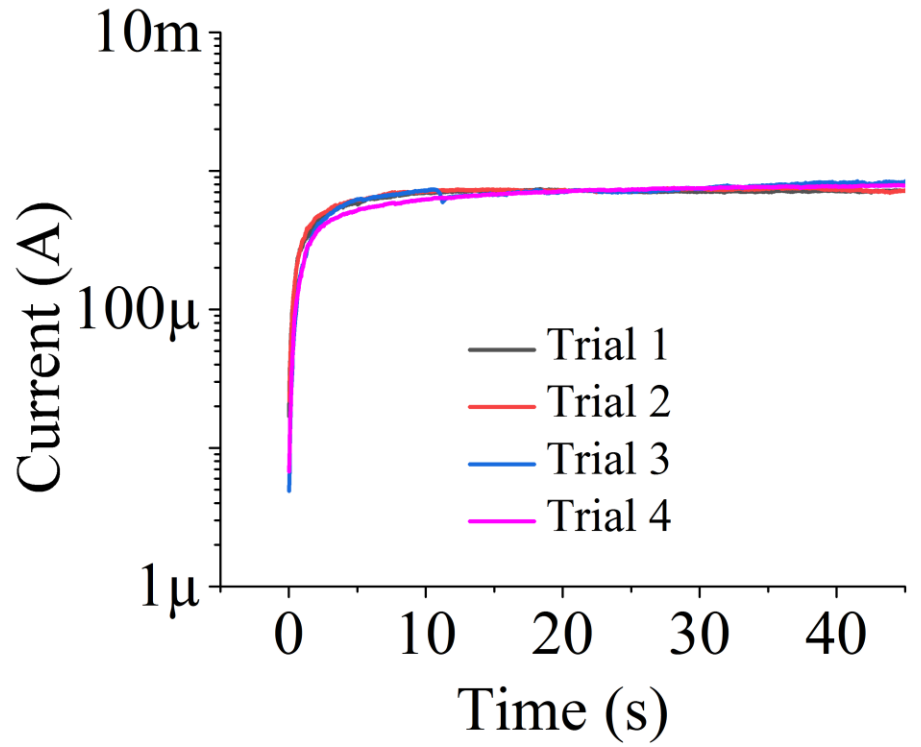


FIG. S57. Concentration = 76 mg/ml

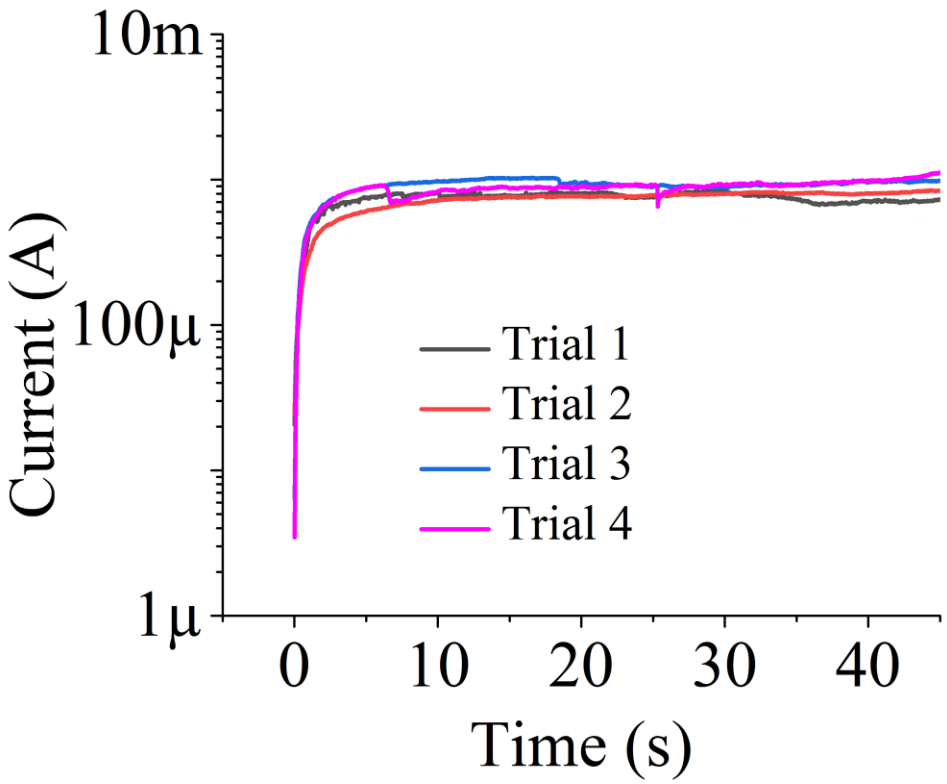


FIG. S58. Concentration = 89 mg/ml

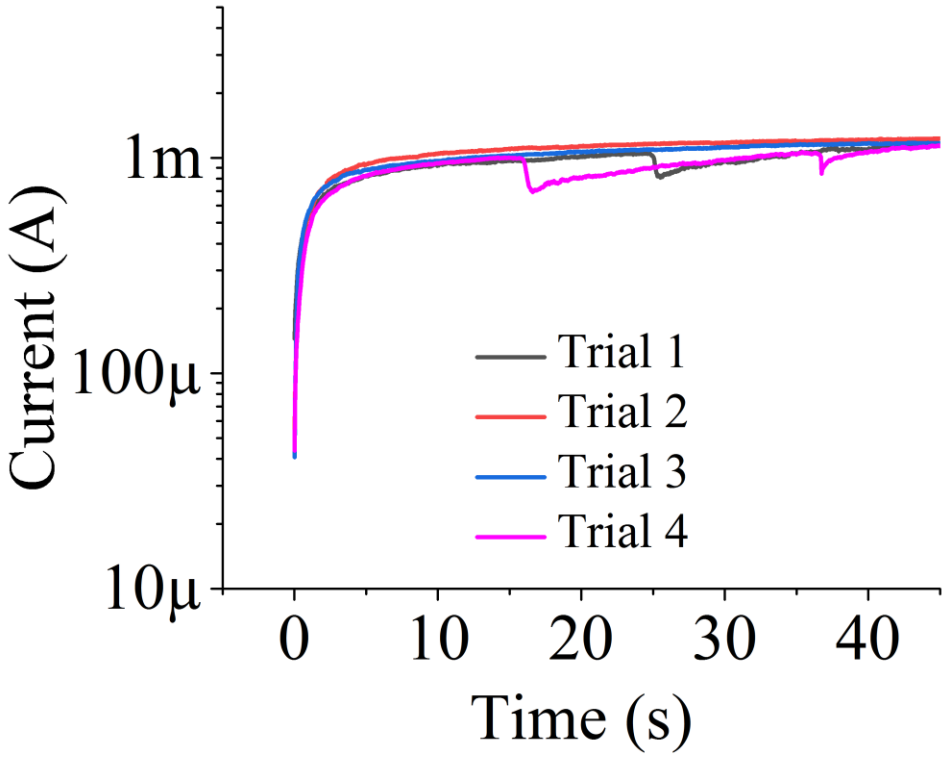


FIG. S59. Concentration = 101 mg/ml

B. Resistance

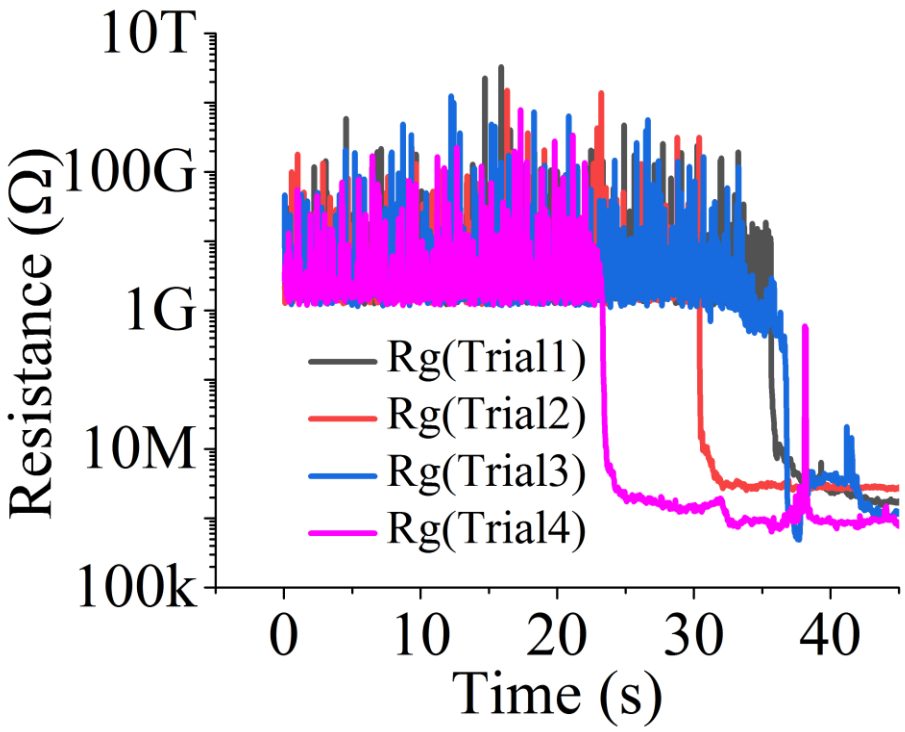


FIG. S60. Concentration = 3 mg/ml

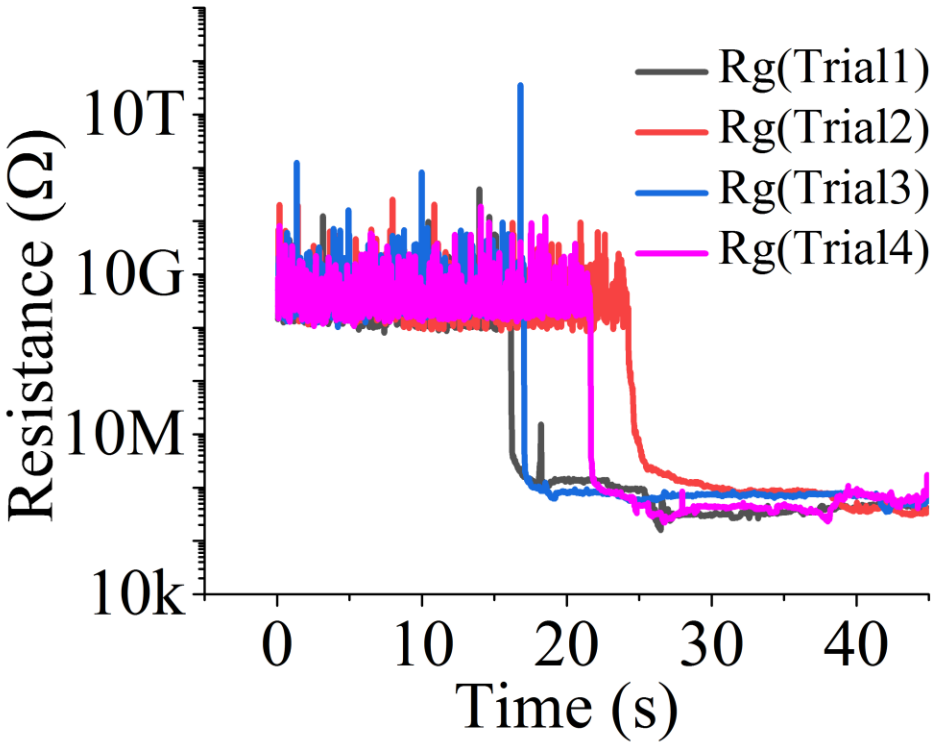


FIG. S61. Concentration = 6 mg/ml

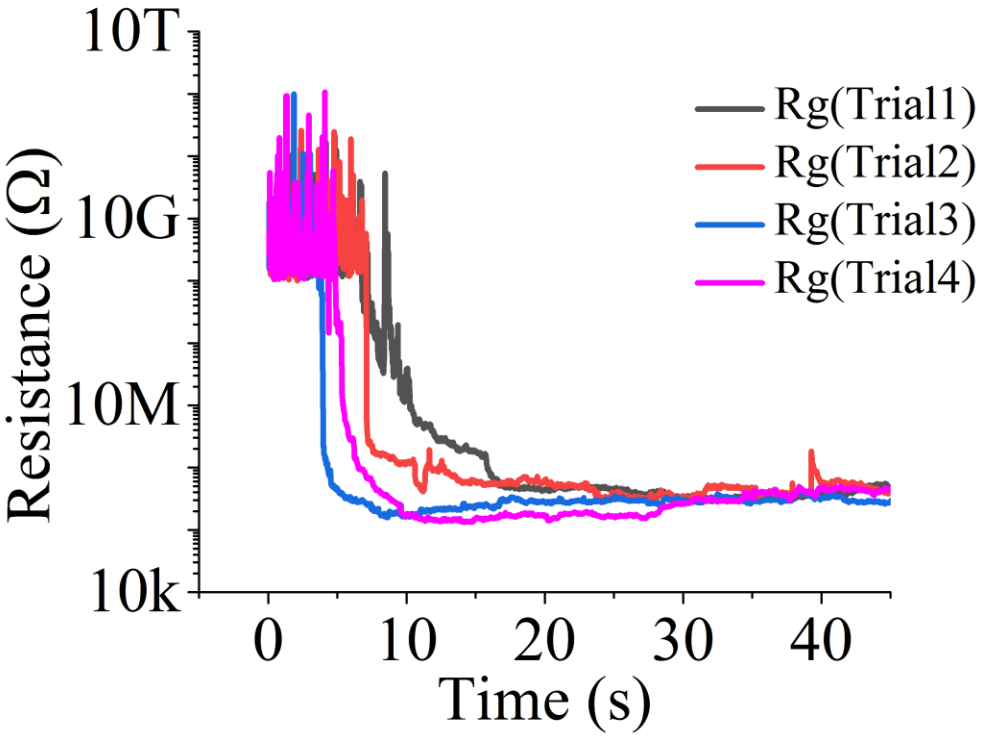


FIG. S62. Concentration = 13 mg/ml

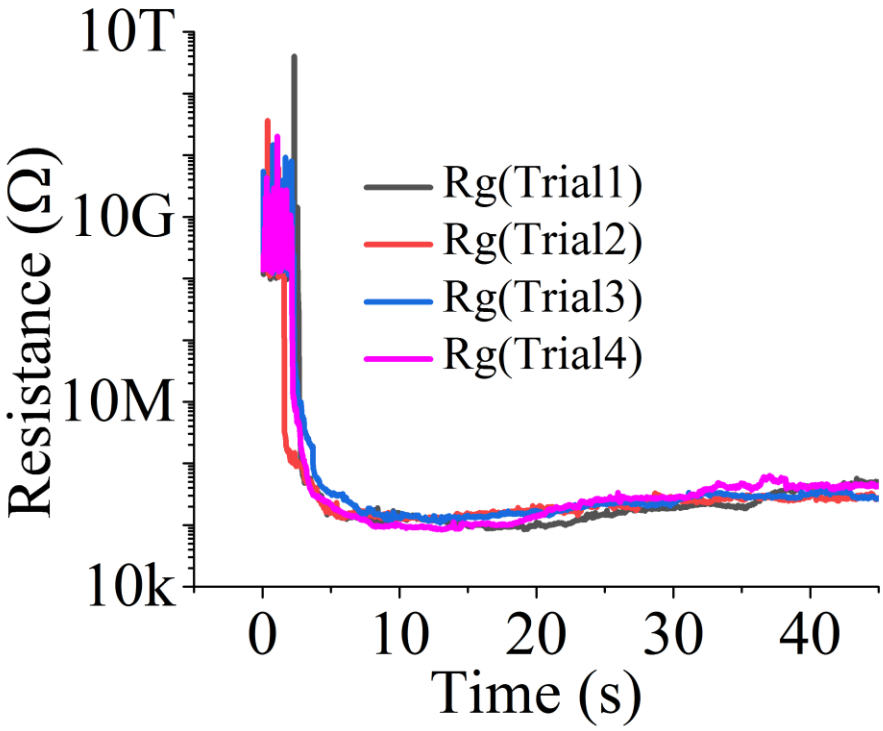


FIG. S63. Concentration = 19 mg/ml

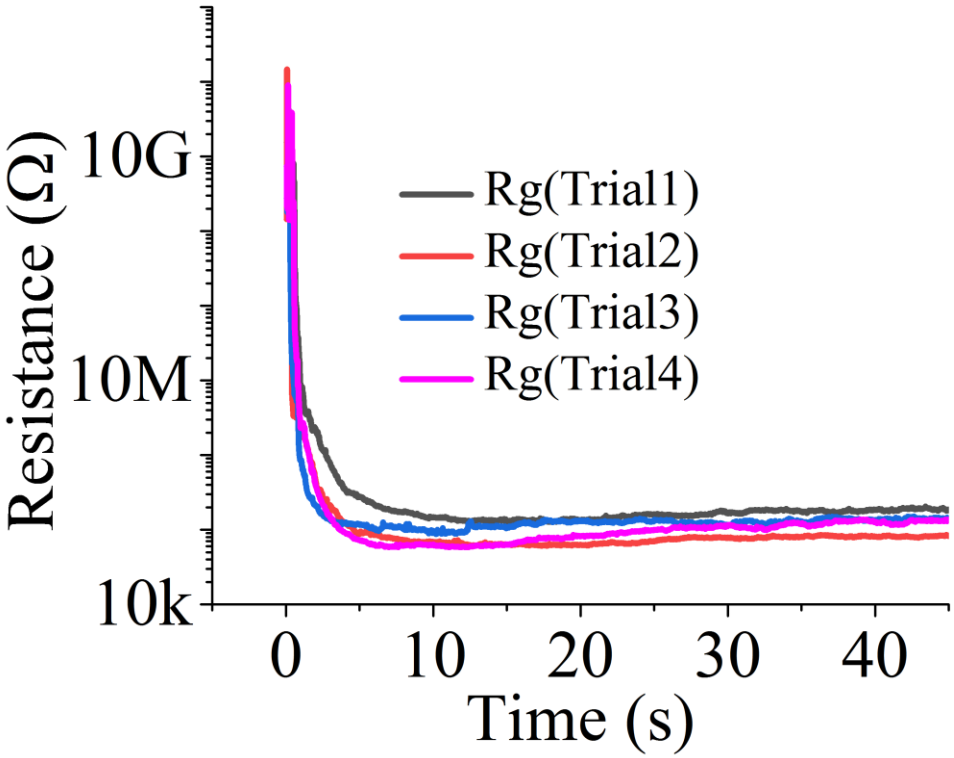


FIG. S64. Concentration = 25 mg/ml

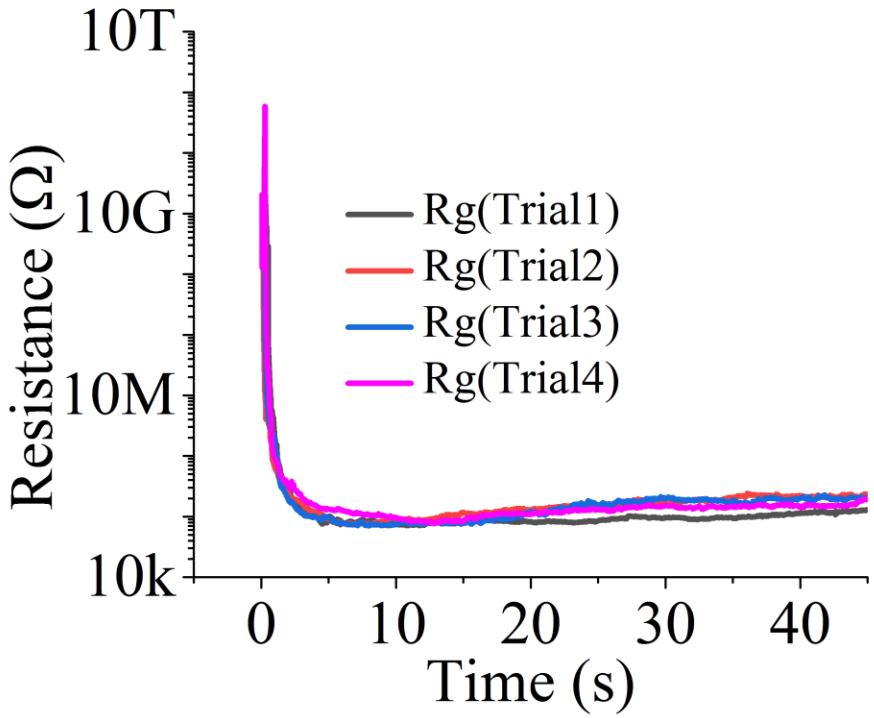


FIG. S65. Concentration =32 mg/ml

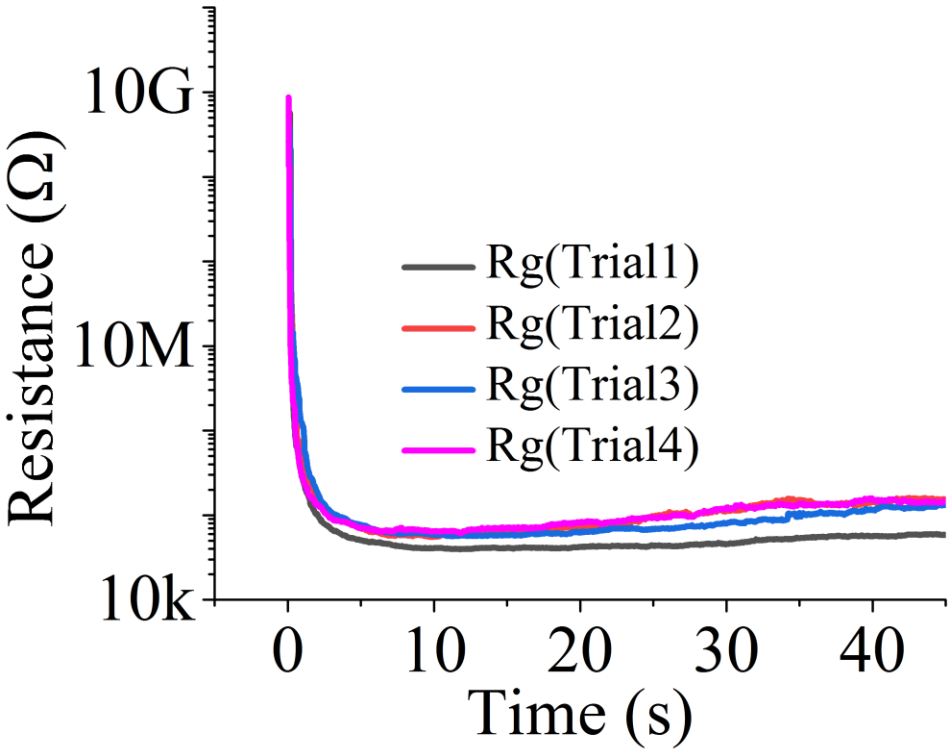


FIG. S66. Concentration = 44 mg/ml

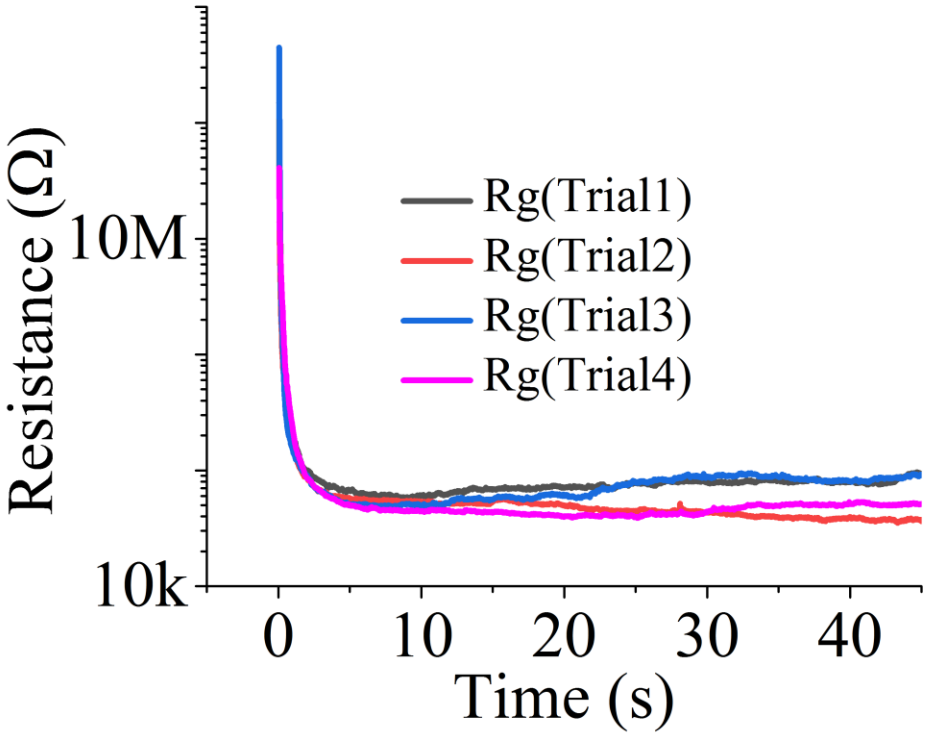


FIG. S67. Concentration = 51 mg/ml

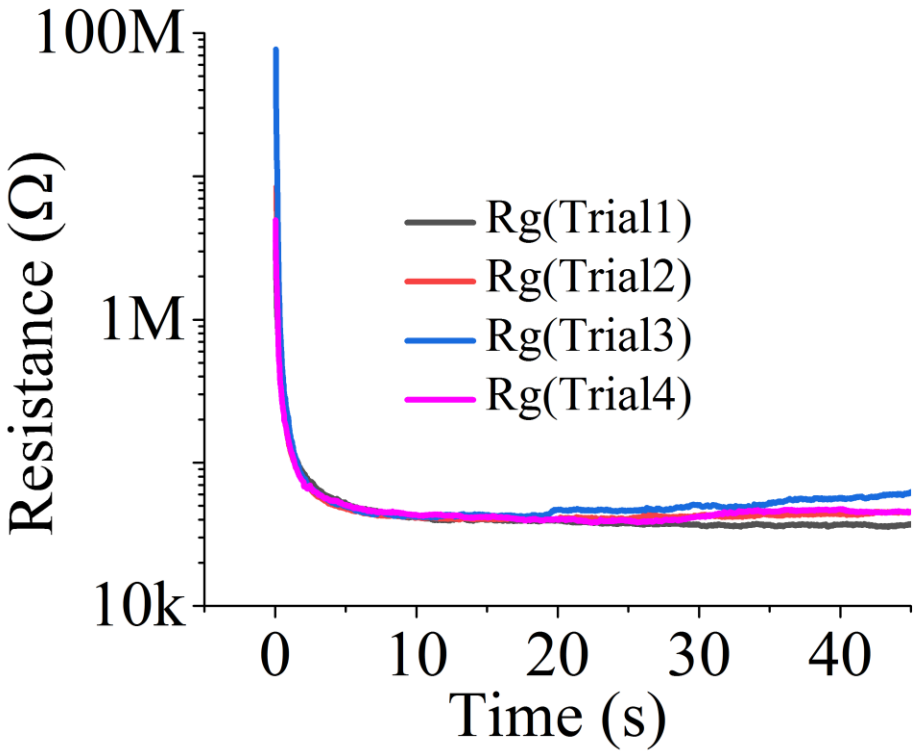


FIG. S68. Concentration = 63 mg/ml

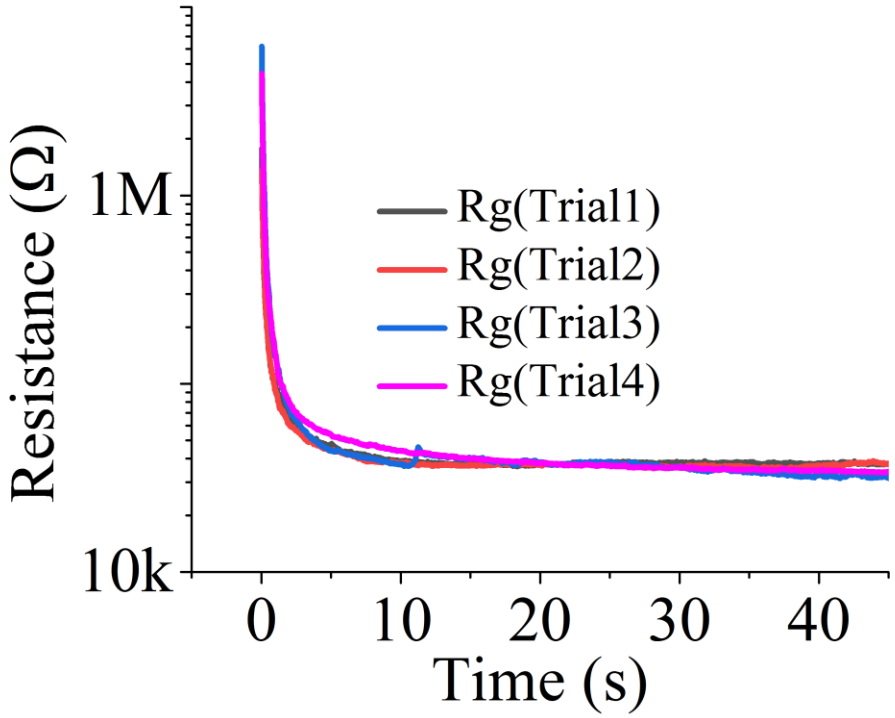


FIG. S69. Concentration = 76 mg/ml

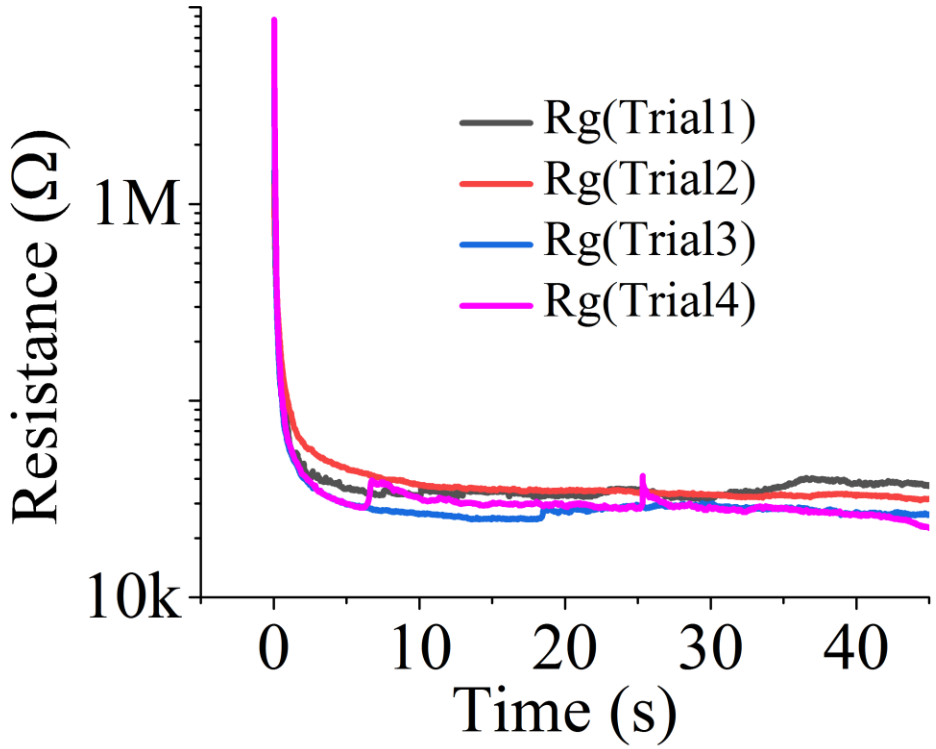


FIG. S70. Concentration = 89 mg/ml

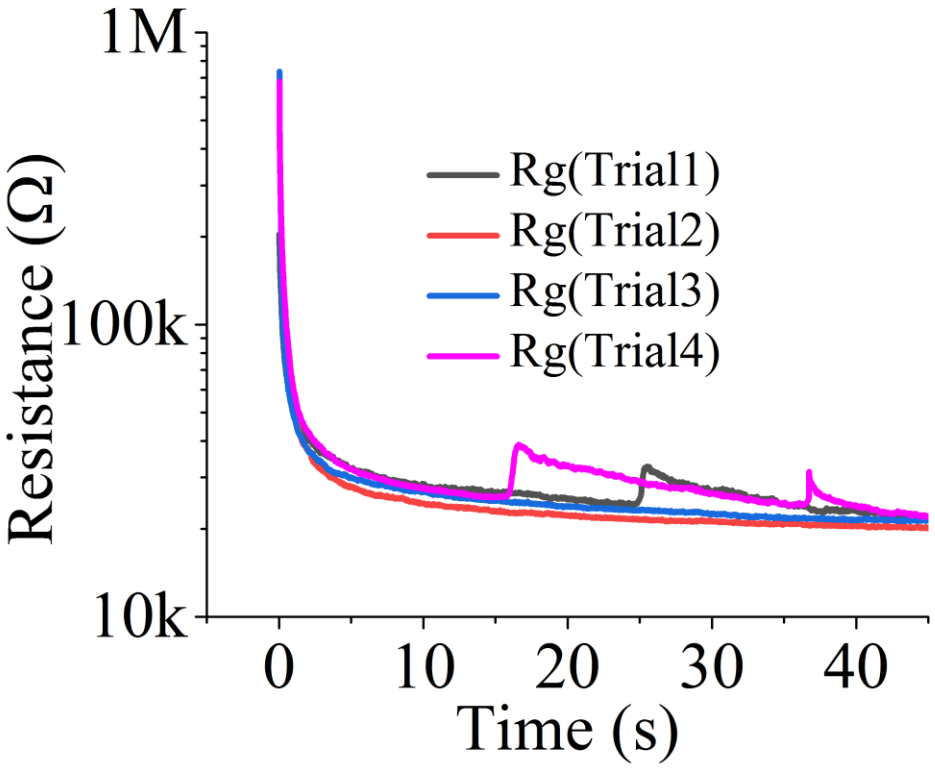


FIG. S71. Concentration = 101 mg/ml

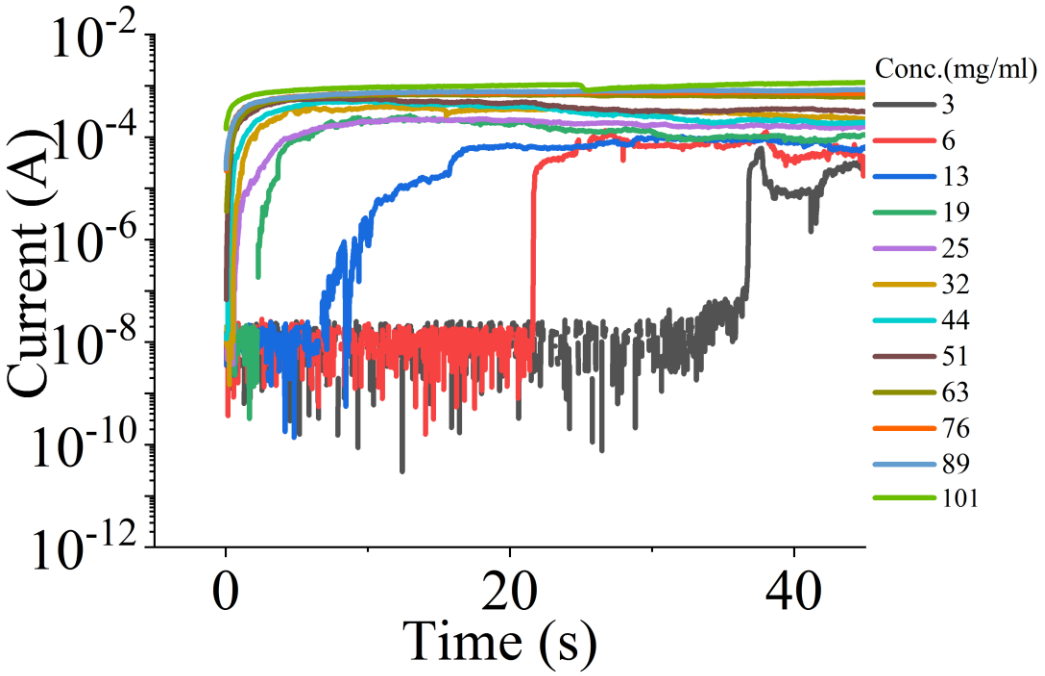


FIG. S72. Cumulative current vs time plot for concentrations

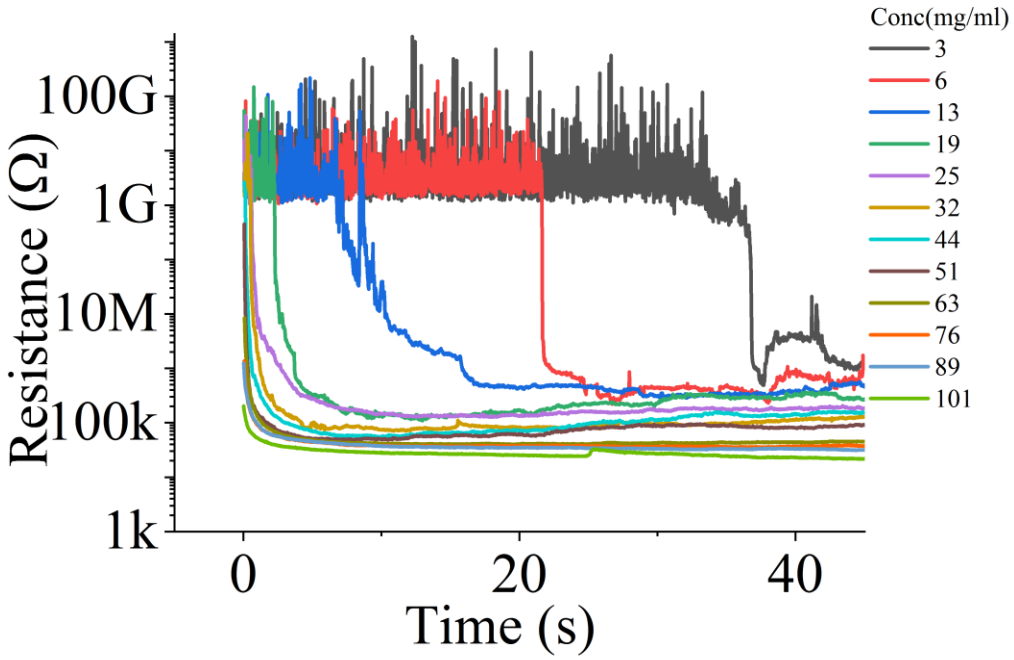


FIG. S73. Cumulative Resistance vs time plot for concentrations

S3. Graphite Bridge SEM Images

There is no sintering in the case of self-healing with graphite dispersions. Since the bridges are not as permanent as in the case of copper, rinsing of the oil with isopropyl alcohol before SEM is not done as it would damage the bridge. The oil residue results in charging and is seen as the bright regions in the images.

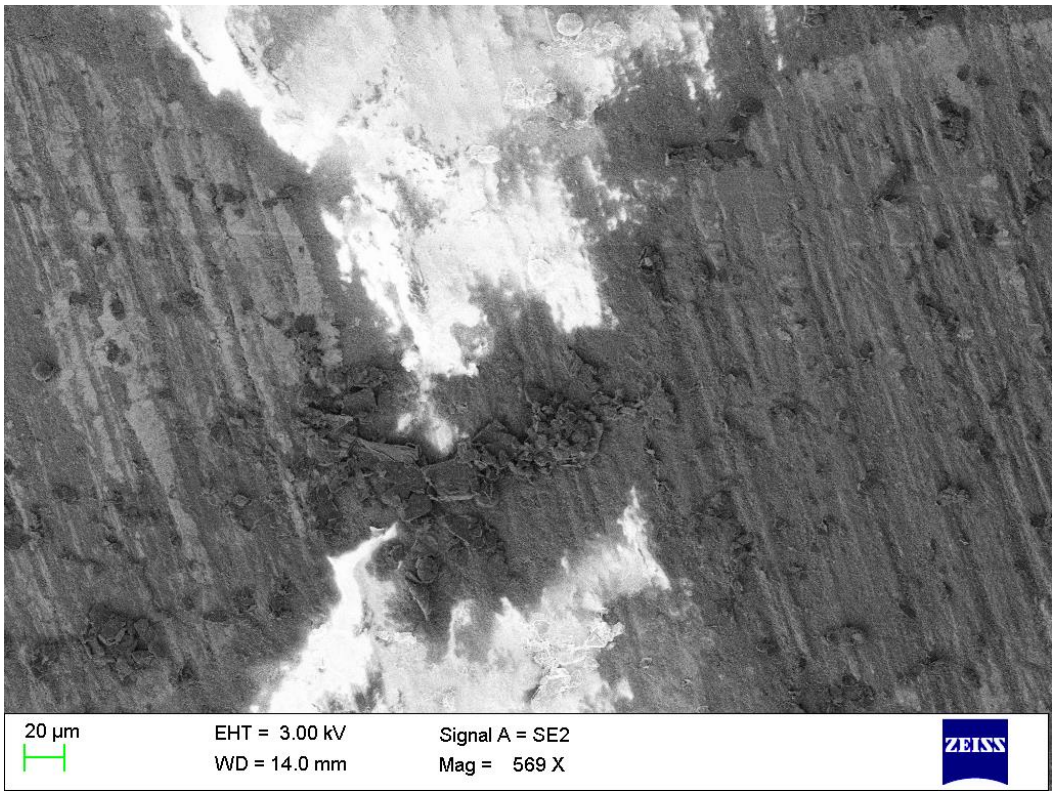


FIG. S74. Graphite bridge SEM 1

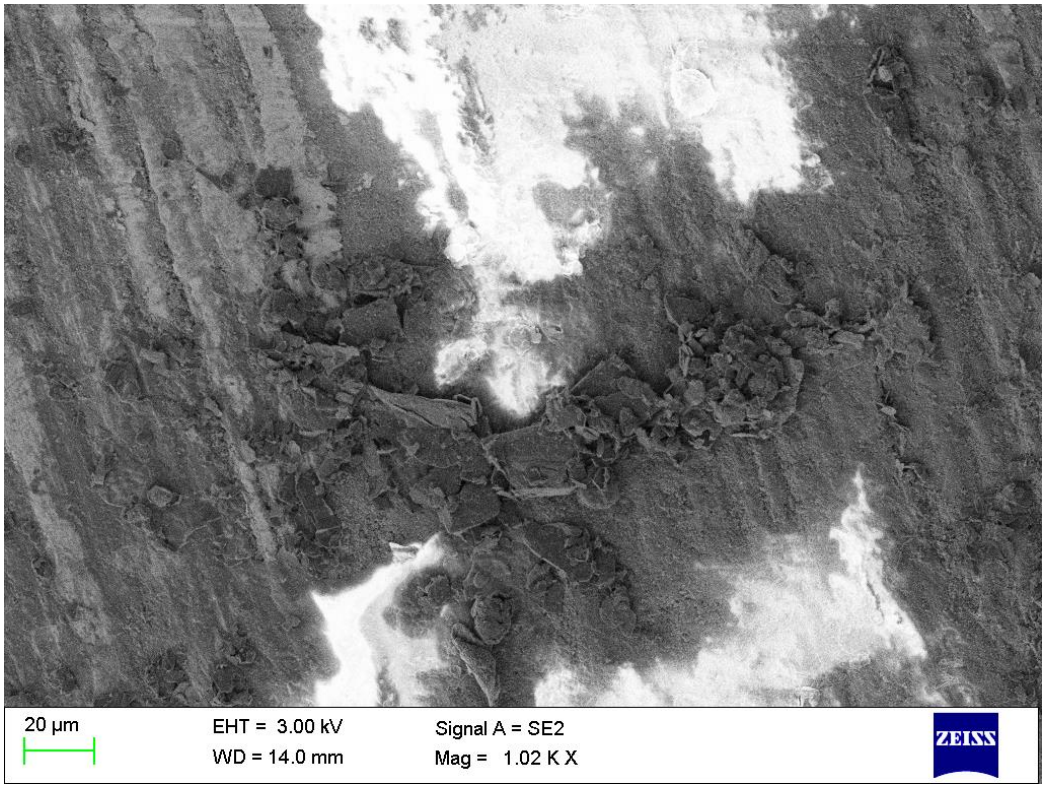


FIG. S75. Graphite bridge SEM 2

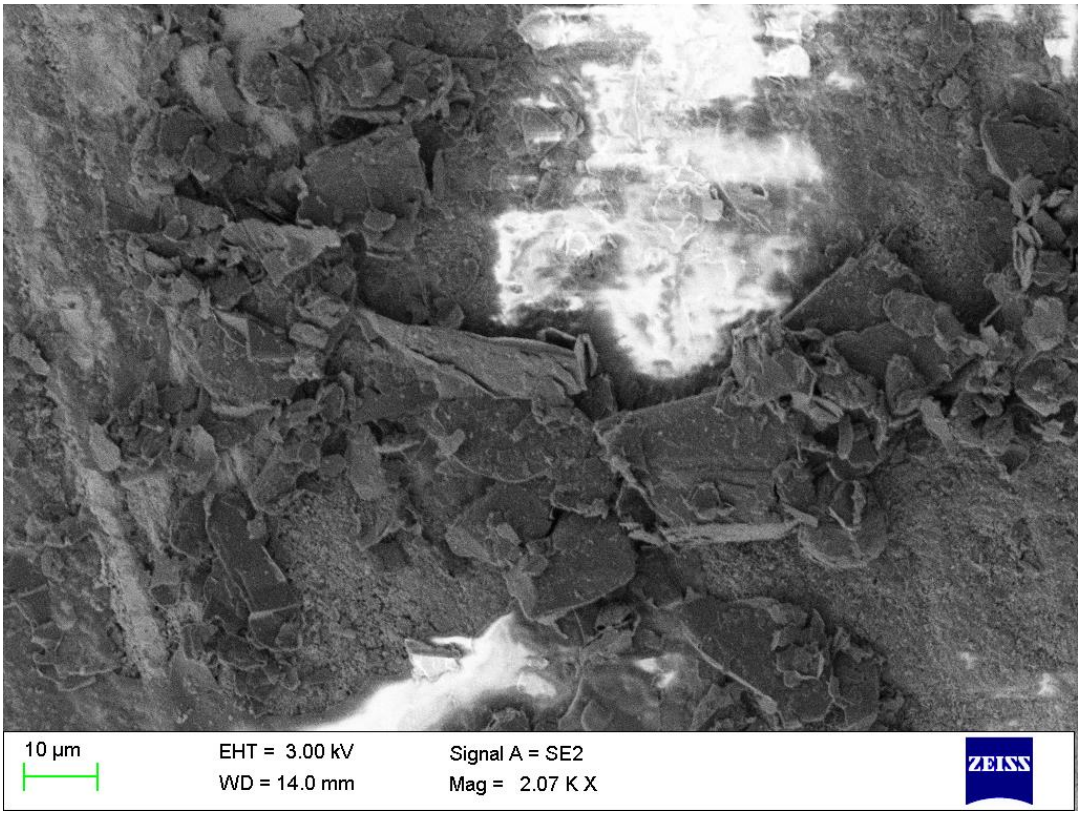


FIG. S76. Graphite bridge left side SEM

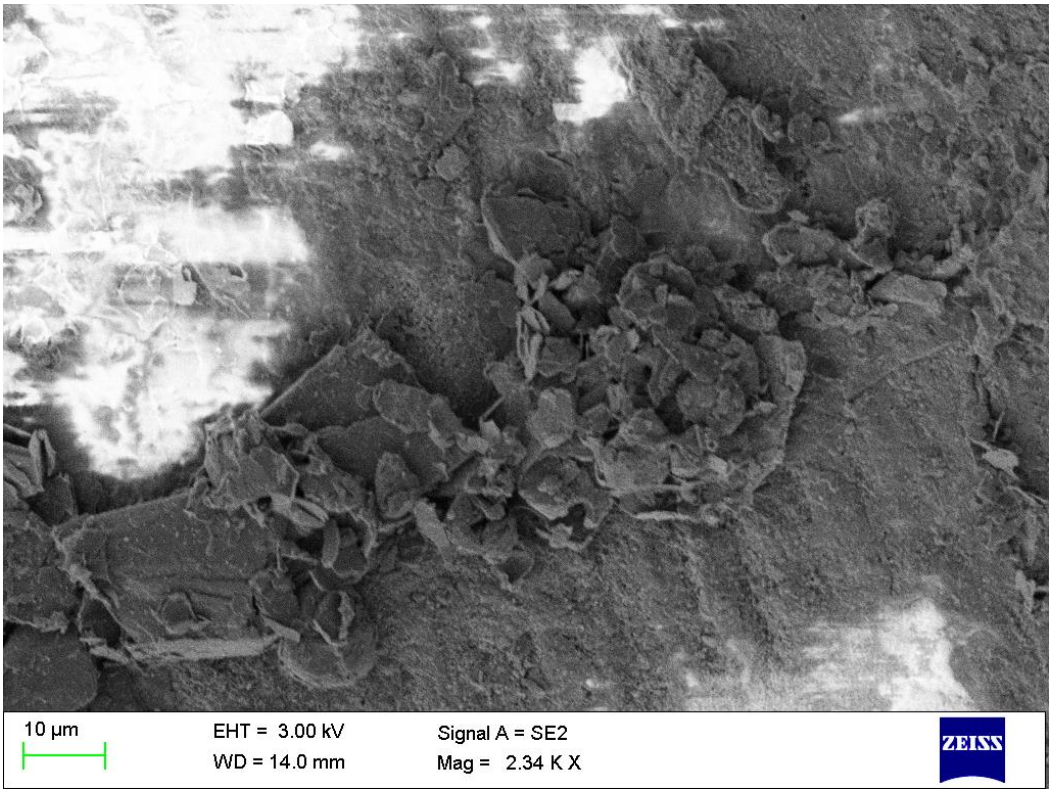


FIG. S77. Graphite bridge right side SEM

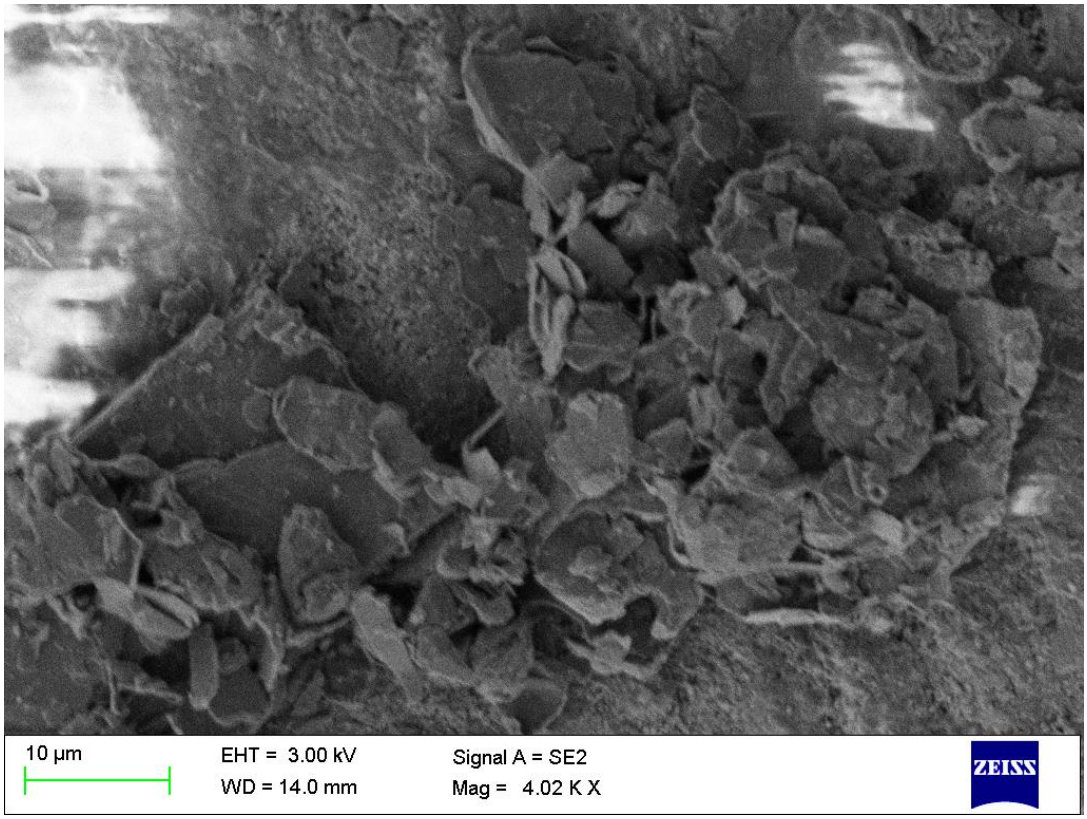


FIG. S78. Graphite bridge right side SEM more zoom

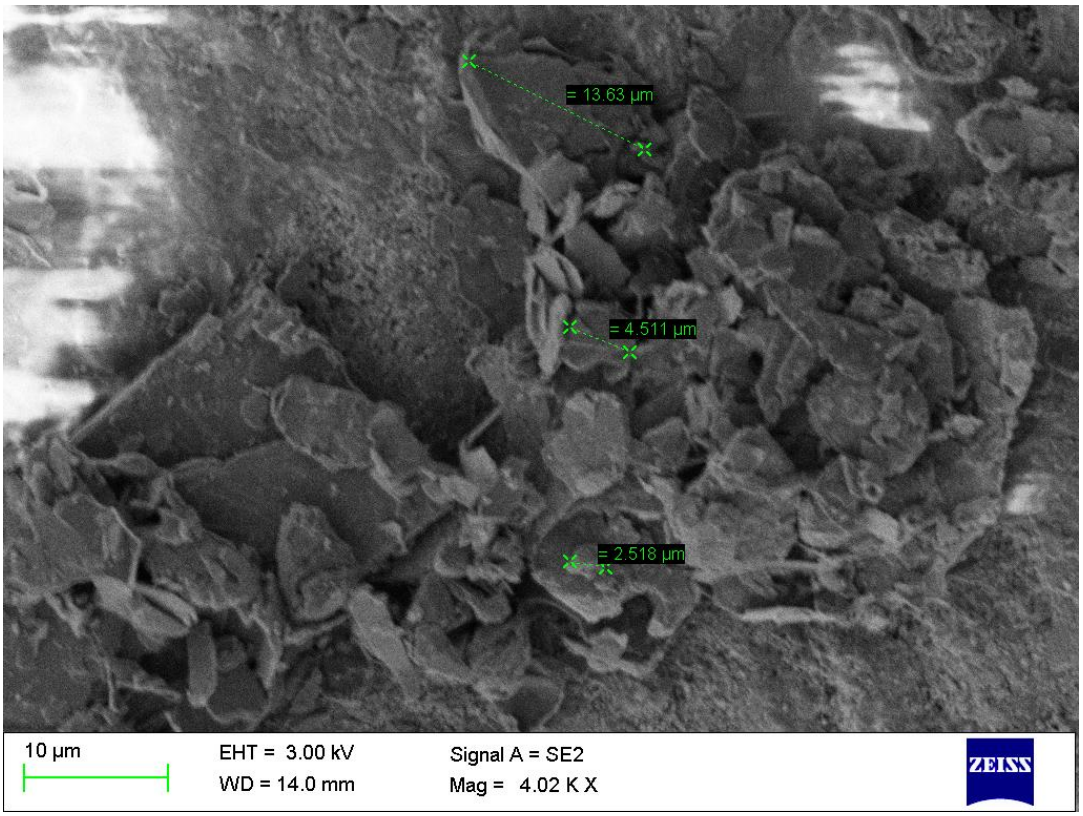


FIG. S79. Graphite bridge right side SEM more zoom with particle size

S4. X-Ray Photoelectron Spectroscopy (XPS) of COPPER PARTICLES

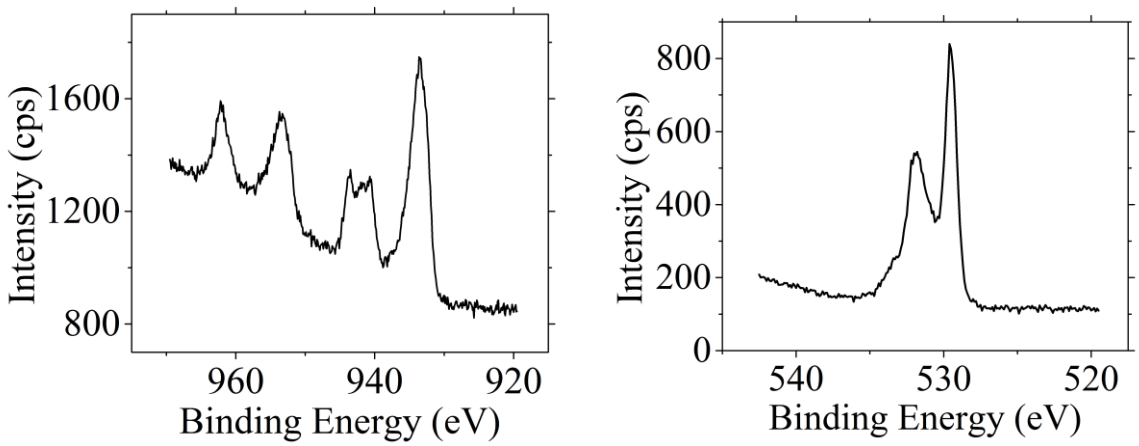
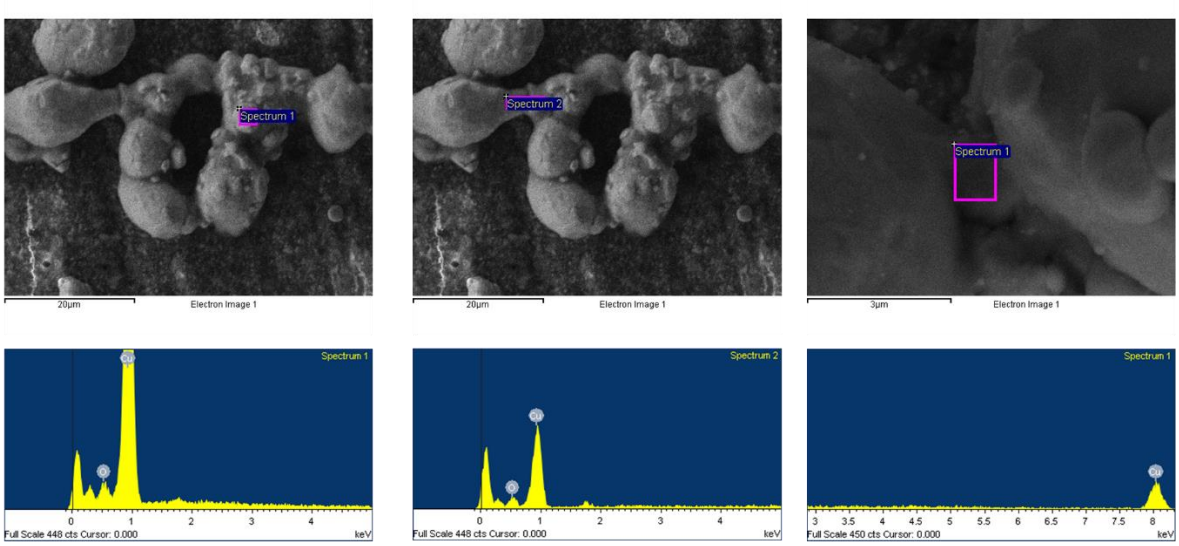


Fig. S80. X-Ray Photoelectron Spectroscopy (XPS) of copper particles. The particles show clear peaks of Oxygen and Copper. This can be compared to reference https://srdata.nist.gov/xps/EnergyTypeValSrch.aspx.

S5. Energy-Dispersive X-Ray Spectroscopy (EDX) SEM of the HEAL

EDX SEM of the heal. Since all experiments (starting from dispersion preparation to healing) are carried at close to ambient conditions, the presence of oxide over the metallic particles is unavoidable. After sintering, during SEM measurements it is expected that the surface still have oxide (as (i) the sintering only results in a necking at the point of contact (ii) and there is sufficient delay between the healing and the EDAX characterization). Yet, since the heal shows excellent conductivity after sintering - it is speculated that inside the sintered neck the oxide should have broken down.



Cu: atomic % = 74.2 , weight % =91.95
O: atomic % = 25.8, weight % =8.05

Cu: atomic % = 81.07 , weight % = 94.45
O: atomic % = 18.93, weight % = 5.55

Cu: atomic % = 21.54, weight % = 93.53
O: atomic % = 78.46, weight % = 6.47

Fig. S81. Energy dispersive X-Ray Spectroscopy of the surface of the heal

S6. CROSSTALK EXPERIMENTAL SETUP

FIG. S82. Plastic mold for PDMS Mask

FIG. S83. Copper track with PDMS

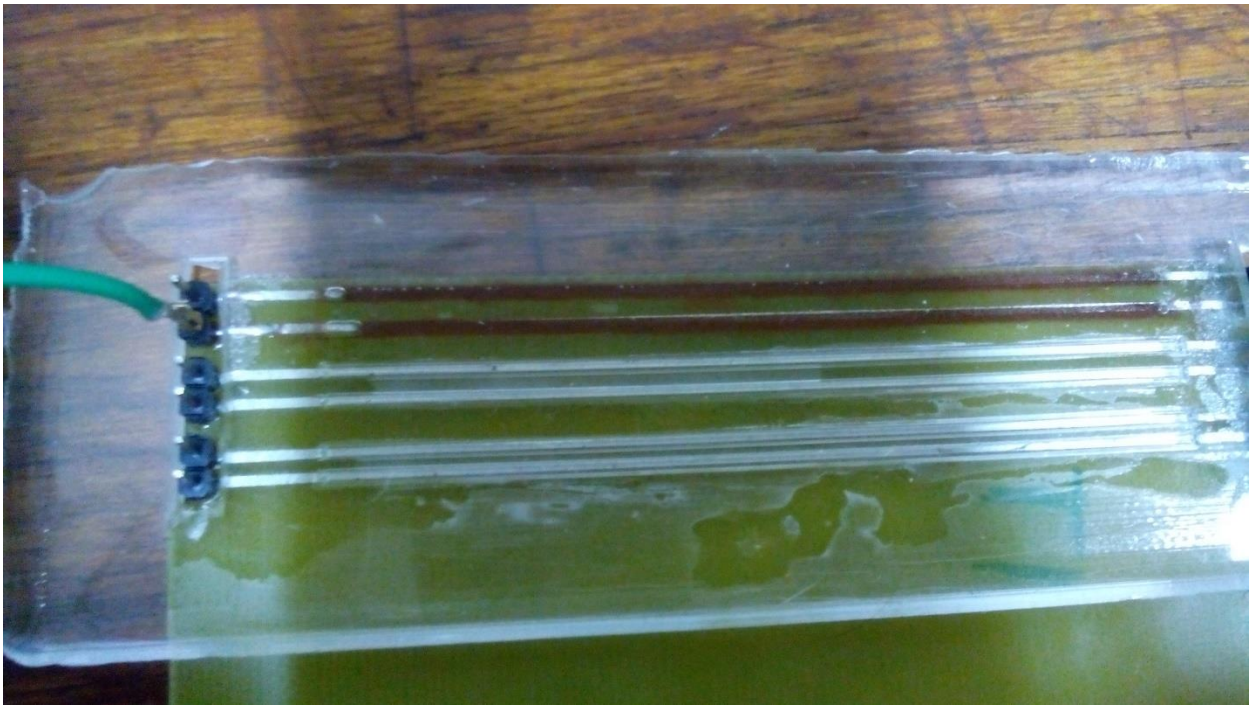


FIG. S84. Copper track with PDMS channel filled up with dispersion

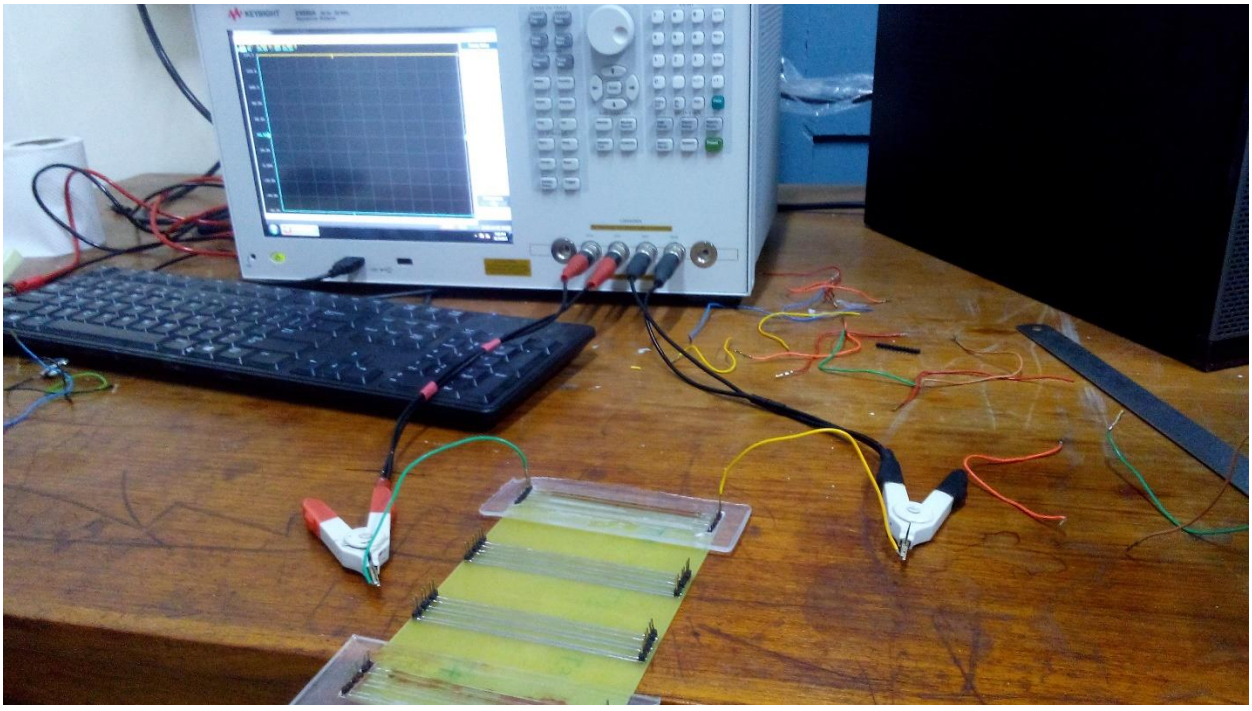


FIG. S85. Experimental Setup.