



**UNIVERSITY OF LEEDS**

This is a repository copy of *Supercurrent in ferromagnetic Josephson junctions with heavy metal interlayers*.

White Rose Research Online URL for this paper:  
<http://eprints.whiterose.ac.uk/131686/>

Version: Supplemental Material

---

**Article:**

Satchell, N [orcid.org/0000-0003-1597-2489](https://orcid.org/0000-0003-1597-2489) and Birge, NO (2018) Supercurrent in ferromagnetic Josephson junctions with heavy metal interlayers. *Physical Review B - Condensed Matter and Materials Physics*, 97 (21). 214509. ISSN 1098-0121

<https://doi.org/10.1103/PhysRevB.97.214509>

---

© 2018, American Physical Society. This is an author produced version of a paper published in *Physical Review B - Condensed Matter and Materials Physics*. Uploaded in accordance with the publisher's self-archiving policy.

**Reuse**

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

**Takedown**

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing [eprints@whiterose.ac.uk](mailto:eprints@whiterose.ac.uk) including the URL of the record and the reason for the withdrawal request.



[eprints@whiterose.ac.uk](mailto:eprints@whiterose.ac.uk)  
<https://eprints.whiterose.ac.uk/>

Supplementary Material for: “Supercurrent in ferromagnetic Josephson junctions with heavy metal interlayers” by N. Satchell and N. O. Birge

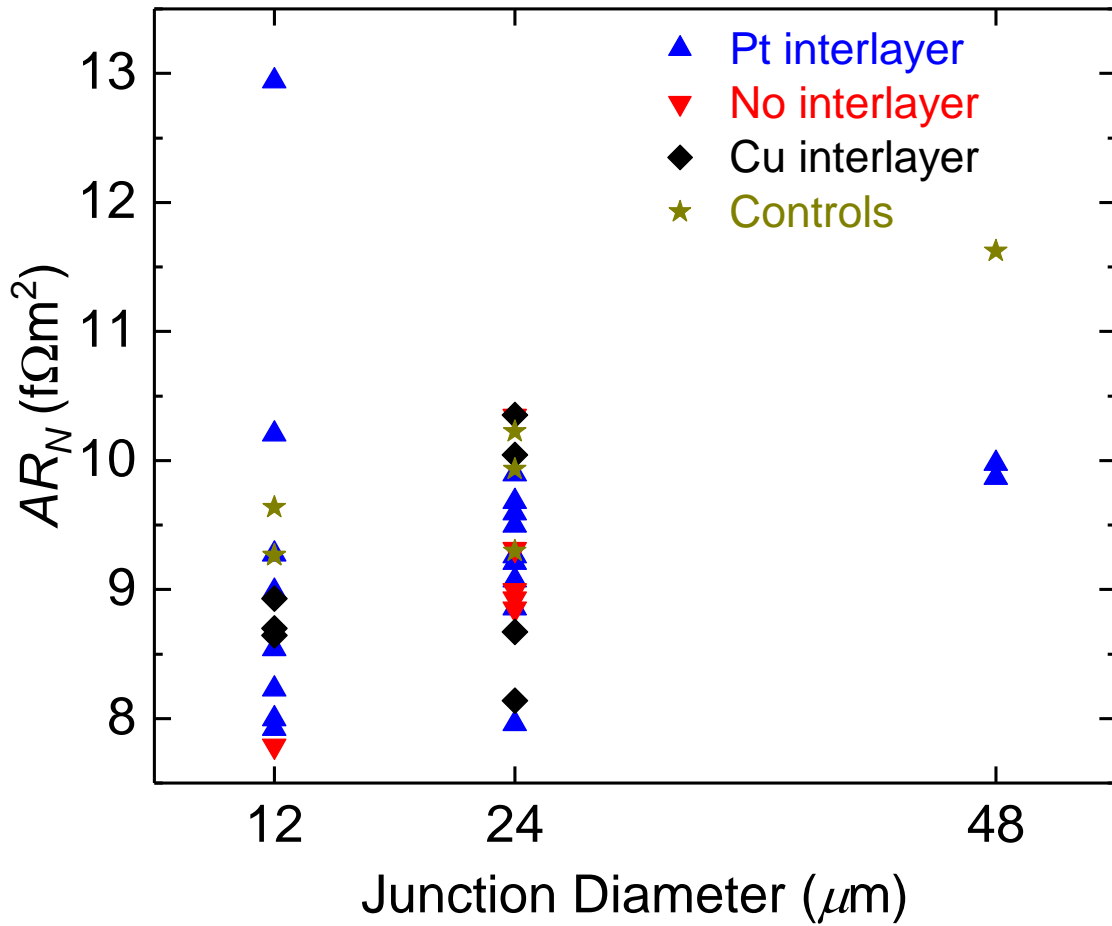


FIG. 1. The area-resistance product with junction diameter for all Josephson junctions presented in the main text. The symbols are chosen to match those used in figures in the main text. The small variation in  $AR_N$  indicates that sample-to-sample fabrication reproducibility is very high in this study.

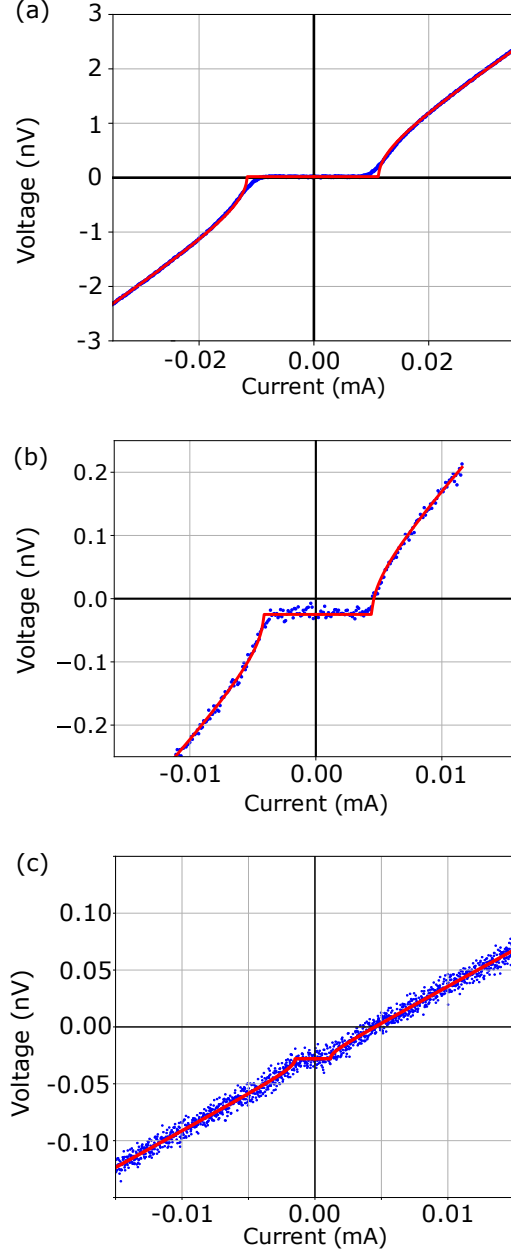


FIG. 2. Representative current-voltage curves. Data (blue points) are fitted using the square root function (red lines) to determine  $I_c$ . (a) Data acquired on a  $12\mu\text{m}$  diameter Josephson junction with structure  $S\text{-Pt}(0.5)\text{-Co}(5)/\text{Ru}(0.6)/\text{Co}(5)\text{-Pt}(0.5)\text{-S}$  at 0 Oe applied field. (b) Data acquired on a  $24\mu\text{m}$  diameter Josephson junction with structure  $S\text{-Co}(4)/\text{Ru}(0.6)/\text{Co}(4)\text{-S}$  at -2 Oe applied field. And (c) data acquired on a  $48\mu\text{m}$  diameter Josephson junction with asymmetric structure  $S\text{-Co}(5)/\text{Ru}(0.6)/\text{Co}(5)\text{-Pt}(0.5)\text{-S}$  at 0 Oe applied field.

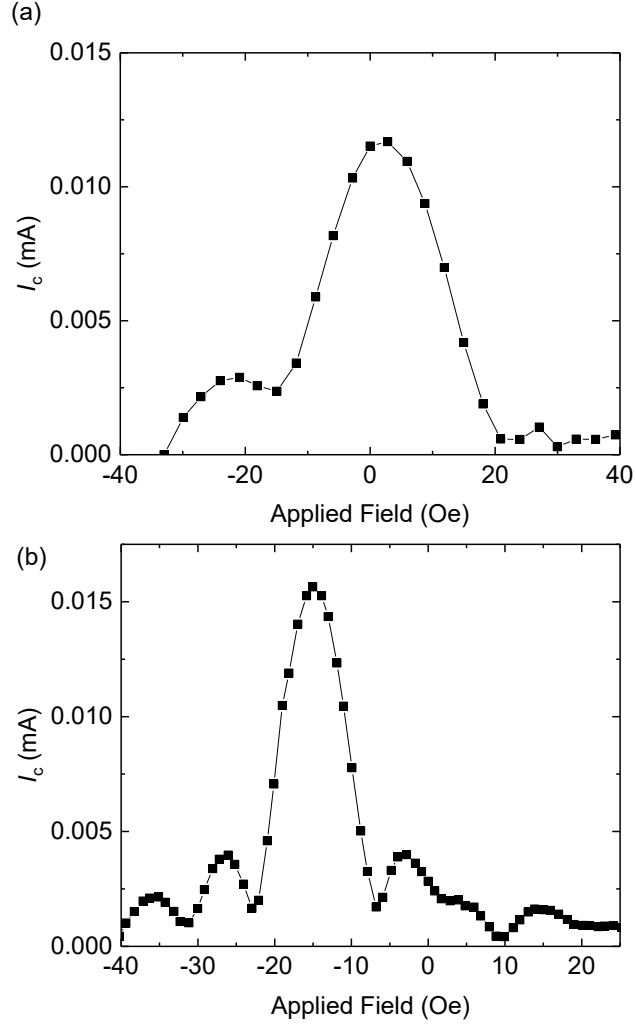


FIG. 3. The critical current,  $I_c$ , is plotted vs the applied in-plane field for the representative samples (a) a  $12\mu\text{m}$  diameter Josephson junction with structure  $S\text{-Pt}(0.5)\text{-Co}(5)/\text{Ru}(0.6)/\text{Co}(5)\text{-Pt}(0.5)\text{-S}$ . And (b) a  $24\mu\text{m}$  diameter Josephson junction with asymmetric structure  $S\text{-Pt}(0.5)\text{-Co}(5)/\text{Ru}(0.6)/\text{Co}(5)\text{-S}$ . Lines through the data are a guide for the eye.

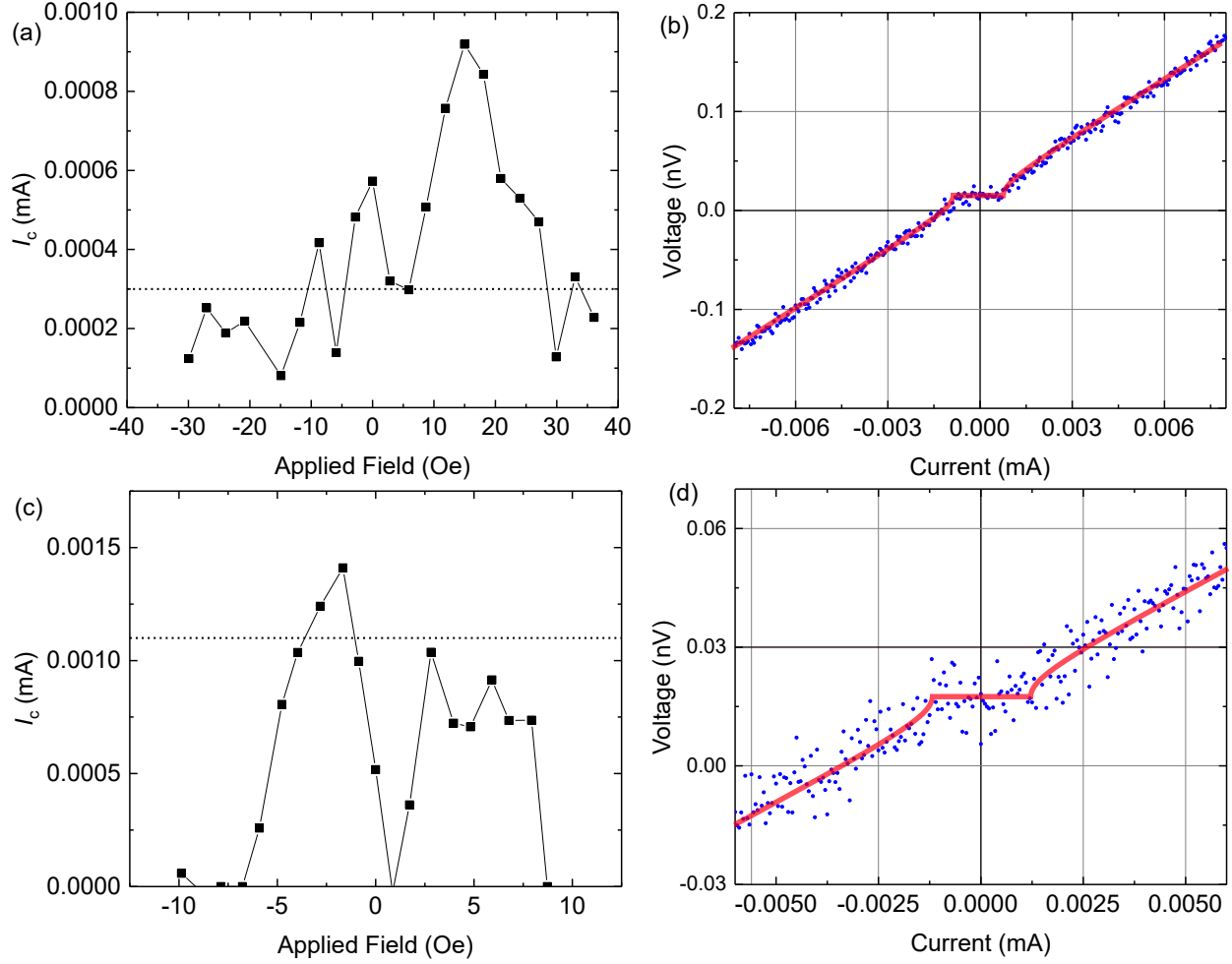


FIG. 4. Data acquired on the (a,b)  $d_{\text{Co}} = 20$  nm and (c,d)  $d_{\text{Co}} = 24$  nm samples described in the main text. (a) The critical current,  $I_c$ , is plotted vs the applied in-plane field for a  $d_{\text{Co}} = 20$  nm,  $24 \mu\text{m}$  diameter Josephson junction. A clear peak in  $I_c$  is observed, centered at applied field 13 Oe. The current-voltage curve at 13 Oe is plotted in (b) along with the square root fit to the data. The square root fit returns  $\chi^2 = 339$  for 321 data points, while a straight line fit to the same data (not shown) returns  $\chi^2 = 533$ . (c) The critical current,  $I_c$ , is plotted vs the applied in-plane field for a  $d_{\text{Co}} = 24$  nm,  $48 \mu\text{m}$  diameter Josephson junction. This sample does not produce a clear peak in  $I_c(H)$ . The current-voltage curve for this sample at -2 Oe is plotted in (d) along with the square root fit to the data. The square root fit returns  $\chi^2 = 247$  for 242 data points, while a straight line fit to the same data (not shown) returns  $\chi^2 = 285$ . The dashed horizontal line in (a,c) represents the approximate resolution of our instrument in determining  $I_c R_N$  (6 pV) and lines connecting data points are as a guide for the eye.

TABLE I. In this table we compare the decay length inside the Co layer of our Josephson junctions to the previous work of Khasawneh, *et al. Phys. Rev. B* **80**, 020506(R) (2009). It is found that the decay length in the absence of any additional interlayers in this work is longer than that reported by Khasawneh, *et al.* however the Pt interlayers do not recover as long a decay length as found in the previous samples with Cu interlayers.

Sample	Co decay length	Source
[Nb(25)/Al(2.4)] <sub>x3</sub> /Nb(20)/Co( $d_{Co}/2$ ) /Ru(0.6)/Co( $d_{Co}/2$ )/Nb(5)/Au(15)	$1.7 \pm 0.2$ nm	This work
[Nb(25)/Al(2.4)] <sub>x3</sub> /Nb(20)/Pt(0.5)/Co( $d_{Co}/2$ ) /Ru(0.6)/Co( $d_{Co}/2$ )/Pt(0.5)/Nb(5)/Au(15)	$1.73 \pm 0.07$ nm	This work
Nb(150)/Co( $d_{Co}/2$ )/Ru(0.6)/ Co( $d_{Co}/2$ )/Nb(25)/Au(15)	$1.18 \pm 0.05$ nm	Khasawneh, <i>et al.</i>
Nb(150)/Cu(5)/Co( $d_{Co}/2$ )/Ru(0.6)/ Co( $d_{Co}/2$ )/Cu(5)/Nb(25)/Au(15)	$2.34 \pm 0.08$ nm	Khasawneh, <i>et al.</i>

TABLE II. In this table we compare the  $I_c R_N$  values for a total Co thickness of 10 nm for our Josephson junctions to the previous work of Khasawneh, *et al. Phys. Rev. B* **80**, 020506(R) (2009). It is found that for all comparable samples the  $I_c R_N$  values in this work are about an order of magnitude lower than those found in the previous work.

Sample	$I_c R_N$ (nV)	Source
Nb(150)/Co(5)/Ru(0.6)/Co(5)/Nb(25)/Au(15)	$0.502 \pm 0.05$	Khasawneh, <i>et al.</i>
[Nb(25)/Al(2.4)] <sub>x3</sub> /Nb(20)/Co(5)/Ru(0.6)/Co(5)/ /Nb(5)/Au(15)	0.0552 - 0.0810	This work
Nb(150)/Cu(5)/Co(5)/Ru(0.6)/Co(5)/Cu(5)/Nb(25)/Au(15)	$9.24 \pm 1$	Khasawneh, <i>et al.</i>
[Nb(25)/Al(2.4)] <sub>x3</sub> /Nb(20)/Cu(2.5)/Co(5)/Ru(0.6)/Co(5)/ Cu(2.5)/Nb(5)/Au(15)	0.603 - 0.725	This work
[Nb(25)/Al(2.4)] <sub>x3</sub> /Nb(20)/Pt(0.5)/Co(5)/Ru(0.6)/Co(5)/ Pt(0.5)/Nb(5)/Au(15)	0.823 - 0.938	This work