Electrical transport through constrictions in the charge-density wave conductor NbSe₃

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Abstract. We have investigated the electrical transport properties of insulating and metallic constrictions of dimensions 100 nm–10 μ m in the charge-density wave (CDW) conductor NbSe₃. The constrictions are made in a variety of ways: focused ion beam, reactive ion etching through a resist mask, and in a mechanically-controlled break junction configuration. We find that the behaviour of the junctions is independent of the fabrication method, and, depending on the size of the constriction, that the low-temperature behaviour of the constrictions is metallic or insulating. At 4.2 K we observe peaks in the differential conductance near 100 mV and 200 mV, which vanish as the temperature is increased above the Peierls temperatures 59 K and 145 K respectively. The data is consistent with the interpretation that there are two different regimes, depending on the size of the constriction, demonstrating either tunnelling behaviour, due to CDW-insulator-CDW junctions, or metallic behaviour, due to two normal metal-CDW junctions in series.

1. INTRODUCTION

Recent advances in fabrication techniques allow the study of mesoscopic aspects of charge-density wave (CDW) transport [1, 2]. Since tunnelling through fully-gapped CDW conductors, like blue bronze, suffer from band-bending effects at the interface akin to semiconductor-insulator-metal junctions, work is limited to NbSe₃, which remains metallic down to 4.2 K. Previous in-chain tunnelling studies and mechanical point contact experiments have either not extended to sufficiently high bias ranges to observe energy-gap related features or have been cited as having poor stability [1, 3]. We present here transport results of constrictions between $\sim$ 100 nm and 10 μ m in NbSe₃ formed using three different approaches: Focused Ion Beam (FIB) fabrication, Resist Mask and subsequent reactive ion etched (RM) fabrication, and Mechanically Controlled Break Junction (MCBJ) samples. More details on these approaches may be found in [4]. Broadly speaking, we observe two kinds of low-temperature behaviour, depending on the size of the junction: in sufficiently small junctions, and broken MCBJ samples, the differential conductance dI/dV is minimum at zero bias; in larger junctions, and re-contacted MCBJ samples, dI/dV is maximum at zero bias. Common to all junctions is the observation of peaks in dI/dV at biases symmetric around $\sim$ 100 mV and $\sim$ 200 mV.

2. RESULTS AND DISCUSSION

Figure 1 shows data collected from FIB, MCBJ and RM samples of increasing size. Fig 1(a) shows results for a FIB constriction of size < 100 nm: dI/dV is suppressed around zero bias and shows peaks at ± 105 mV and ± 195 mV. This behaviour is reproduced in a MCBJ after breaking, also shown in Fig. 1(a). The zero bias resistance versus temperature, shown in Fig. 1(b), decreases monotonically and bears little resemblance to the bulk behaviour of NbSe₃, which is metallic down to 4.2 K. The peak positions, Fig. 1(c), also decrease monotonically with temperature, indicating a strict association between each dI/dV peak and the lower and upper CDW transitions in bulk NbSe₃ at 59 K and 145 K. Figure 1(d) shows

Figure 1. (a) ~ 100 nm FIB constrictions and broken MCBJ sample dI/dV vs bias voltage, 4.2K; (b) $R(T)$ at 0V and 200mV of FIB sample in (a); (c) Temperature variation of peak voltages of FIB sample in (a); (d) $\sim 1 \mu\text{m}$ RM and $8 \mu\text{m}$ FIB sample dI/dV vs bias voltage, at 4.2 K and 15 K respectively, insets show $R(T)$ behaviour at 0V; (e) position of peaks vs temperature in both large FIB and RM samples of (d).

transport in larger RM and FIB constrictions, of lateral dimensions $1 \mu\text{m} \times 0.5 \mu\text{m}$ and $8 \mu\text{m} \times 1 \mu\text{m}$ respectively, whose zero-bias resistance is closer to the expected bulk behaviour. Nonetheless, the observed transport through each of these constrictions clearly shows peaks at around the same voltages as observed in the insulating constrictions, which also have similar temperature dependences (see Fig. 1(e)) despite their higher absolute conductance.

We conclude that the size solely determines the behaviour of electrical transport in these systems, independent of constriction-fabrication method. At small sizes constrictions behave like CDW-insulator-CDW tunnel barriers, showing expected dI/dV peaks at twice the CDW energy gaps. As constriction size increases, low bias transport crosses over to bulk-like behaviour and the system forms a CDW-normal metal and normal metal-CDW junction in series, again contributing dI/dV features at twice the CDW energy gaps.

Acknowledgments

We thank S. V. Zaitsev-Zotov and S. Artemenko for fruitful discussions. This work was supported by INTAS-NIS, the Netherlands Organization for Scientific Research (NWO) and the National Science Foundation (NSF). We thank J. van Ruitenbeek for the use of the equipment in the MCBJ work.

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