Fast prototyping of nanoscale InSb devices using focused ion beam lithography

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1 Introduction

InSb has low effective mass, high mobility, and strong spin-orbit coupling, making it an ideal material for **spintronics**[1]. Recently there have been numerous device schemes which have be proposed for generating **spin polarised currents** for spin injection in quantum technologies[2,3,4]. At the heart of these schemes is the **quantum point contact (QPC)** which require nanoscale lithography and gated structures. As demonstrated in Fig. 1, QPCs consists of a source and drain gate surrounding a narrow constriction of width comparable to the de Broglie wavelength of an electron. In this constriction, the two-dimensional electron gas (2DEG) created in the heterostructure becomes one-dimensional and characteristic conductance quantization is observed[5,6]. Here we present a complete fabrication toolkit which employs **focused ion beam (FIB) lithography** as a flexible direct write technique for rapid prototyping of QPCs from Hall bars.

Two approaches for fabricating QPCs have been explored. The first involves defining QPCs using **direct etch** writing of InSb quantum wells. A FIB assisted XeF_2 chemistry was used to form side gates with air gaps. The second technique uses **FIB assisted deposition** to form a siloxane gate dielectric, as well as direct write of metalization using platinum to form split top gates. Compatibility of InSb with these processes has been confirmed investigation of the electronic properties using **Shubnikov de Haas** and **quantum Hall**.

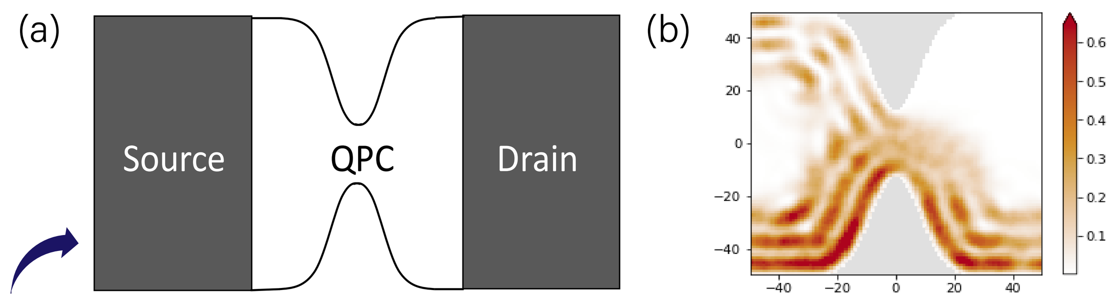

Figure 1. (a) A schematic showing the basic geometry of a QPC. (b) Initial simulations of electron density in an InSb based QPC generated using the software package 'kwant.'

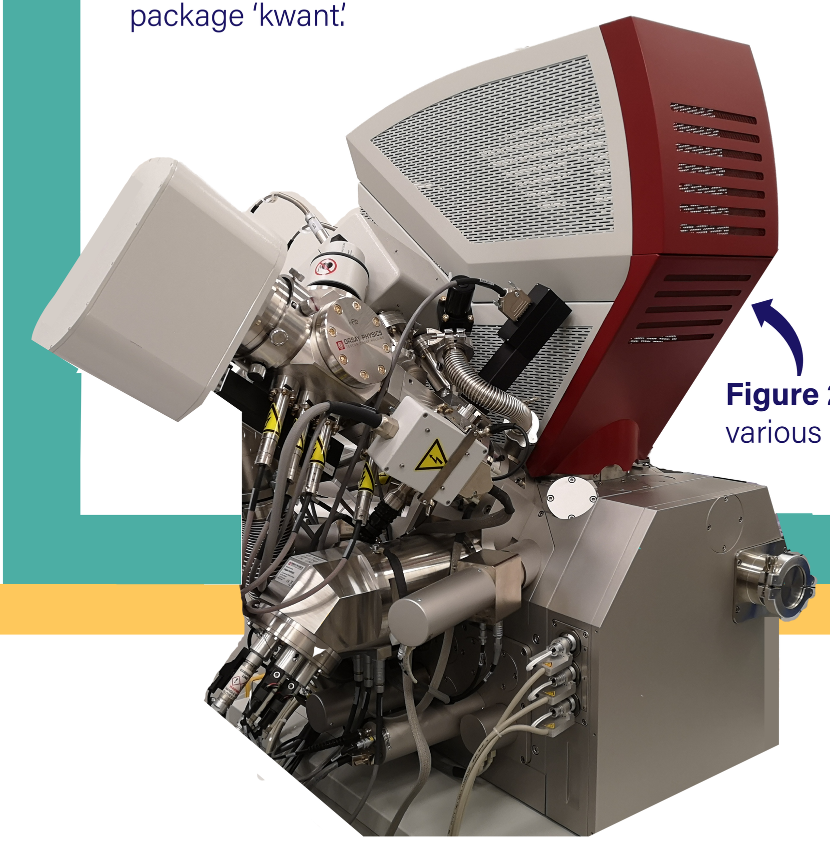

Figure 2. The Xe plasma FIB used for the various QPC fabrication techniques.

2 Methods

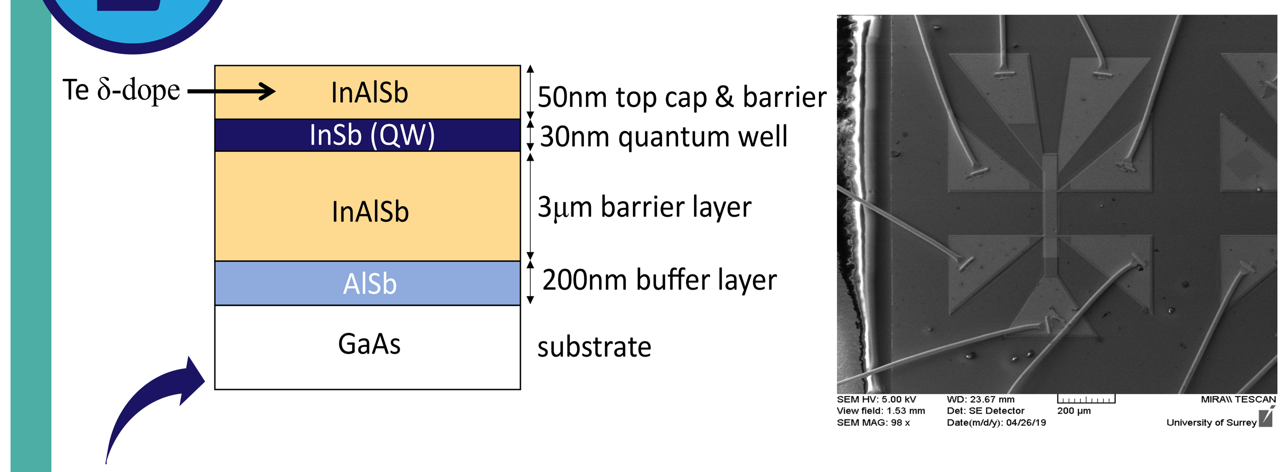

Figure 3. Layer structure of the InSb Hall bars used to create QPCs (left) and SEM image of a Hall bar device from above (right).

InSb Hall bars were used to investigate FIB lithography nanofabrication of QPCs. Figure 3 shows the initial Hall bar devices and figure 4 demonstrates the two FIB lithography techniques used.

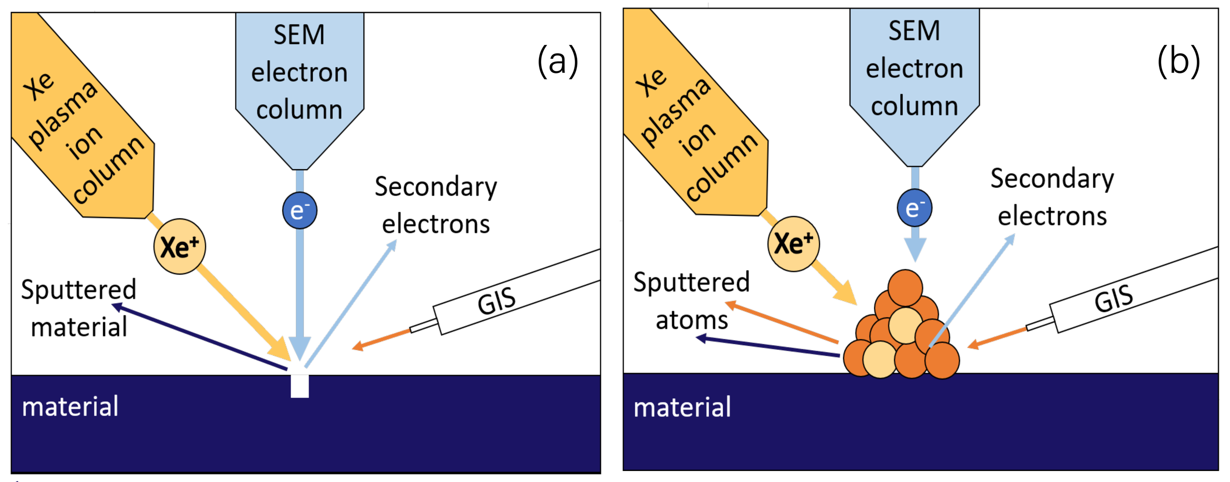

Figure 4. (a) Schematic of FIB assisted t. (b) Schematic of FIB assisted material deposition, adapted from [7].

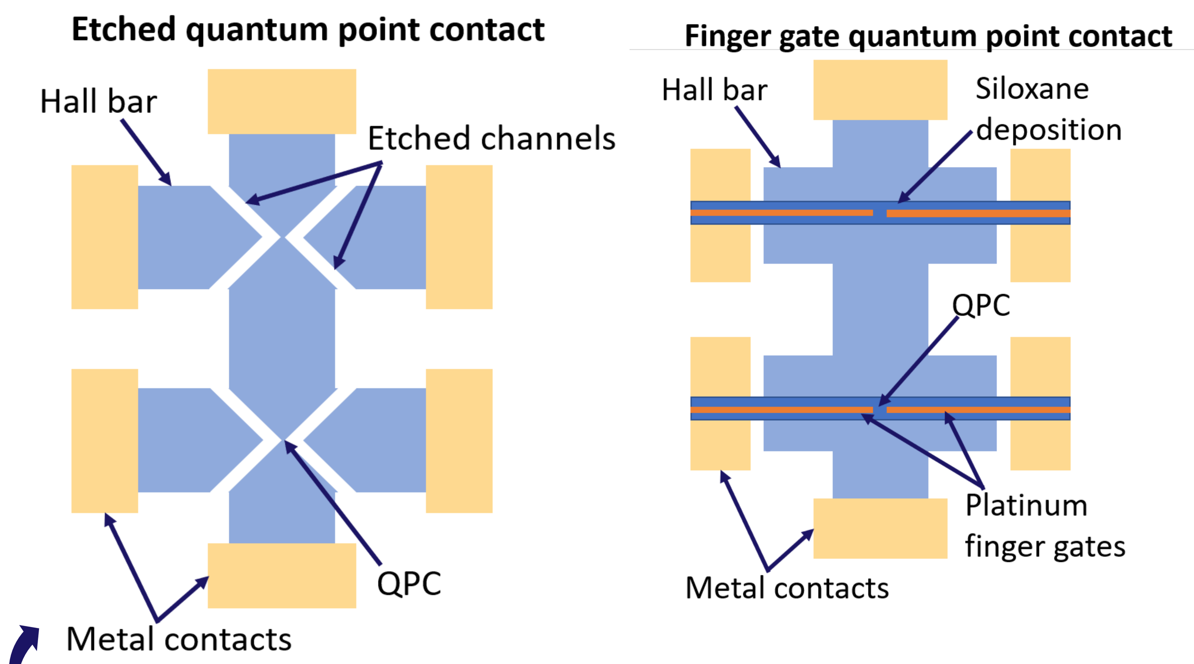

Figure 5. Schematics of the two ways used to define QPCs from Hall bars.

3 Results

A novel direct-write method for fabricating nanoscale features in InSb using FIB lithography is in development. Previously in the literature, various devices of this type have been reported in similar materials but these were fabricated using methods such as wet and dry etching which do not provide the flexibility and speed of the FIB. Due to its strong Rashba and Dresselhaus spin-orbit interaction InSb is an ideal candidate for semiconductor spintronics but it is notoriously difficult to fabricate on the nanoscale. The SEM images and magnetotransport measurements demonstrate a XeF_2 FIB assisted etch and Xe FIB assisted siloxane deposition show promise as rapid prototyping fabrication techniques in InSb and similar materials.

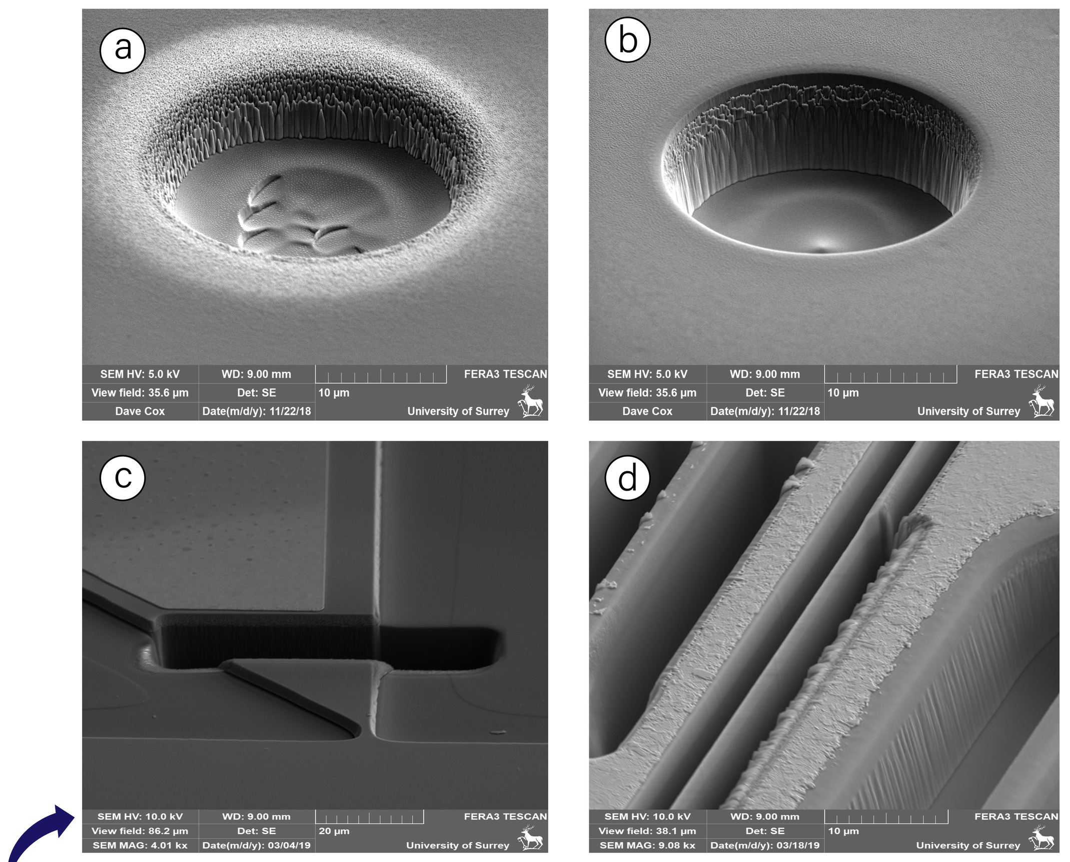

Figure 6. SEM images of initial FIB etching tests. (a) Xe FIB milling of bulk InSb without additional GIS chemistry. (b) XeF_2 FIB assisted etch of bulk InSb. (c) Optimised XeF_2 etching of a trench in InSb/InAlSb Hall bar. (d) Demonstration of XeF_2 milling used to create raised ridges as narrow as 200nm.

	XeF_2 FIB assisted etching	Xe FIB assisted deposition
Carrier concentration before FIB exposure (m^{-2})	$3.48\pm0.04 \times 10^{15}$	$3.90\pm0.07 \times 10^{15}$
Carrier concentration after FIB exposure (m^{-2})	$3.47\pm0.06 \times 10^{15}$	$3.74\pm0.07 \times 10^{15}$
Electron mobility before FIB exposure (m^2/Vs)	24.3 ± 0.2	25.6 ± 0.7
Electron mobility after FIB exposure(m^2/Vs)	25.8 ± 0.5	28.0 ± 0.6

Magnetotransport measurements were obtained before and after FIB exposure at 5K. Electron mobilities calculated using magnetotransport data collected before and after both siloxane deposition and 'thinning' of Hall bars can be seen in the table.

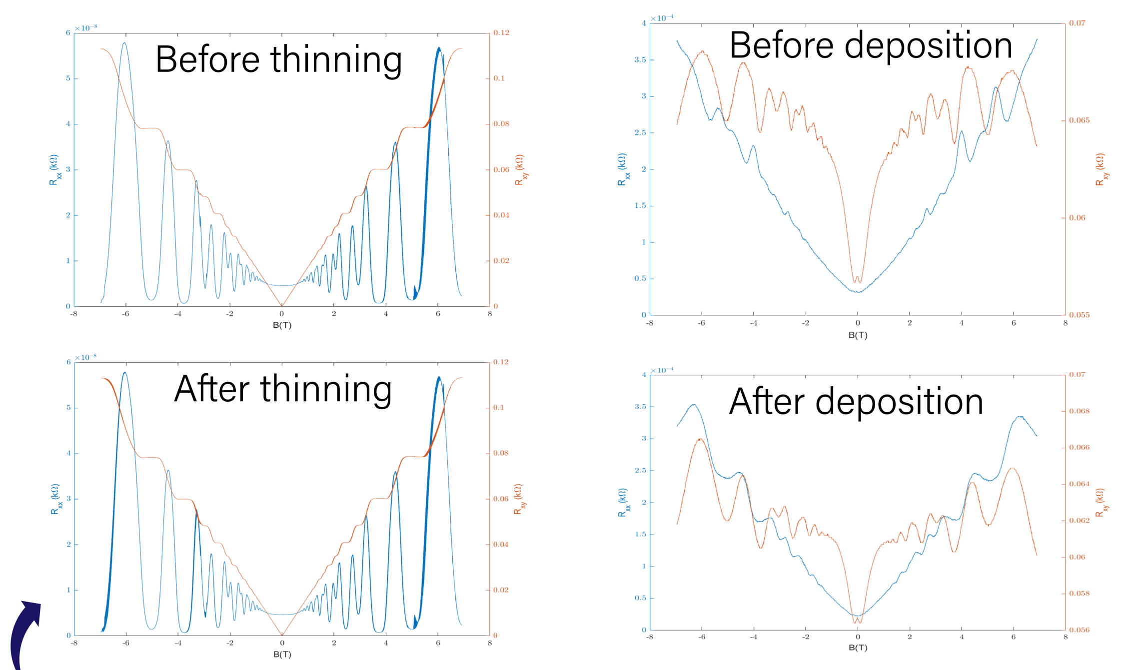

Figure 7. Magnetotransport measurements before (top) and after (bottom) FIB exposure for XeF_2 FIB assisted etching (left) and Xe FIB assisted deposition of siloxane. (right)

4 Conclusion

XeF_2 FIB assisted etching and Xe plasma FIB assisted deposition are viable methods for rapid prototyping of nanoscale devices in InSb.

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