博士論文公聴会の公示(物理学専攻)

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論文題目：Magnetotransport characteristics and surface effects on fabrication in strained Germanium two-dimensional hole gases （歪みゲルマニウム 2 次元正孔ガスにおける磁気輸送特性と作製中の表面効果の研究）

日時：2025 年 8 月 18 日（月）13:30– 15:00（3 限）

場所：理学研究科 H 棟 7 階セミナー室（H701 号室）

主査：大岩顕

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論文要旨

Since the theoretical proposals for quantum computers, and the development of quantum algorithms, which emphasised the superiority of such system over their classical counterparts, many candidates for *qubits* have been proposed, with no universally accepted platform being yet selected. A strong candidate are semiconductor spin qubits, in particular, Ge based quantum dots. Ge presents several advantages, such as strong spin-orbit coupling, fast hole mobility, the possibility for nuclear spin-free isotopic engineering of heterostructures (which improves decoherence times), and a bandgap which lies inside the bandwidth used in telecommunications. This makes Ge quantum well systems specially well-suited as a platform to bridge quantum processing (solid-state qubits) and quantum communication (photonic qubits). Efficient quantum networks, however, require also photospin platforms that are stable under light irradiation, free of phenomena such as persistent photoconductivity. Before the implementation of Ge devices as Poincaré interfaces, however, fabrication recipes must be optimised. While Ge devices have been successfully fabricated by a few groups, there is still a lack of detailed accounts of the physical and chemical processes taken during micro-fabrication and many groups struggle with low yield, gate leakages and similar issues.

The present work addresses both micro-fabrication challenges arising from Ge/SiGe heterostructures, and the characterisation of electronic transport with light irradiation. While Ge was at the inception of solid state electronics as we understand it today, with the first point-contact transistor being made out it, it was soon replaced in the industry by Si, due to the higher quality of its native oxide and its natural abundance. As a consequence, while fabrication techniques for Si became well-developed and optimised, such techniques are not all directly transferable to Ge. Ge native oxides are hygroscopic and thermally unstable, forming at normal laboratory conditions, which can compromise the quality of ohmic metal diffusion, and the overall quality of devices. With this concern, we have investigated different acid cleaning protocols and their effect on samples' surfaces. The recipes were based on different concentrations and dipping time on Hydrofluoric acid, with a 2 minutes dip in 10% aqueous solution, a standard recipe, being the most damaging to surface smoothness. While the cleaning power of all the recipes has been shown to be similar by surface composition analysis via XPS, more gentle approaches, with reduced concentrations (2%) and shorter dipping times proved to be a balanced choice between cleanliness and smoothness. This is an important step as native oxides and organic contaminants can prevent ohmic metals diffusion, compromising device quality. Smoothness, on the other hand, is an important aspect to consider for uniform metal diffusion, as well as for avoiding leakage pathways.

We have also investigated the effect of light irradiation on Hall bar transport measurements. While many devices performed poorly due to gate leakages and high resistance contacts, revealing a very low yield, a few devices were in good conditions enough to allow us to investigate the effect of light irradiation on Hall effect and Shubnikov-de Haas oscillations. Overall, the light experiments show a possible photo-excitation of interfacial trap states, which saturate carrier concentration and mobility after initial irradiation, leading to seemingly stable transport characteristics Ge quantum wells themselves; an interesting result for irradiated quantum dot implementations, indicating a robustness of their characteristics under illumination.