Si－Si 原子サイズ接点の電子伝導特性

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１．　はじめに

接触させた接点を引き離して原子サイズの接点を作製する break junction 法は，金属の原子サイズ接点の有効な作製法として使用されているが，最近 Si カンチレバーを Si 表面に接触・破断させて Si の原子サイズ接点を作る研究が行われており，室温でも Si の数 nm 幅の原子サイズ接点が形成されることが報告されている．本研究は Si 探針－Si 清浄表面間に形成される原子サイズ接点のコンダクタンス測定を行い，その接点長さ依存性を通して Si 接点の伝導特性の解明を試みた．

２．　研究経過

Si 探針は高ドープ p 型 Si ロッドを作製し，これを化学研磨して先端を先鋭化した後，超高真空中で電子ビーム加熱により清浄化を行った．Si(111)表面は n 型・p 型どちらも使用し，超高真空中で加熱して清浄表面を得ている．　接点の形成と伝導度測定は室温・超高真空中で行った．

３．　研究成果

Si-Si 接点の伸長は Si 表面の型とバイアス電圧に依存し，Si 表面が n 型でそれに正バイアスを加えたときに大きな伸びが観測され，他の条件では接点が余り伸びない館に破断するケースが多く見られた．上記の条件は探針－試料の p-n 接合に逆バイアスを加えた状態に相当し，電流による破断促進効果が小さいために接点が伸長するのではないかと推測される． p 型表面の場合にも接点が伸びる場合もあり，そのときには図 1 のようにコンダクタンスは～$10^{-5}G_0$まで低下する（G_0はコンダクタンスの量子化単位）．この低い伝導土壌体を解析するために，Si-Si 接点の伸び，すなわち Si 探針の変位量 L に対するコンダクタンスの変化を調べた結果,図 2 に示すようにコンダクタンス(の平均）の対数 $\log(G/G_0)$は L に対して 2 次関数的な依存性を示すことが明らかになった．このようなコンダクタンスの L 依存性は局在伝導を示す系に特徴的に現れることが知られていることから，探針－試料間に形成される Si-Si 接点は不規則（disordered）構造をとっており，その電子状態が局在しているために接点伝導度が低下していることが推定される．

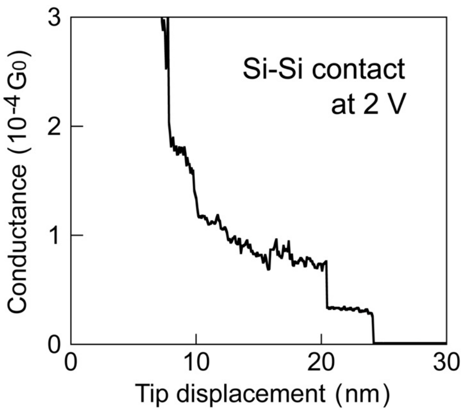

図１　Si-Si 破断接点のコンダクタンス変化.

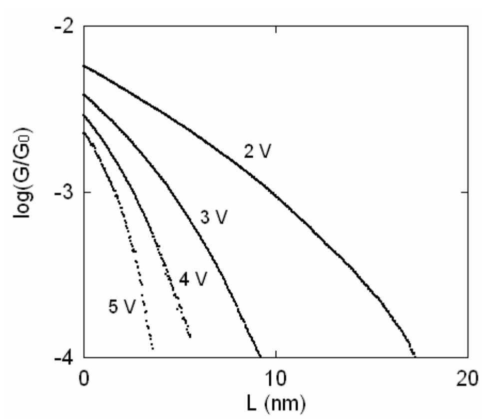

図２　コンダクタンスの接合距離依存性.

４．　まとめ

Si 探針－Si 表面間に形成される原子サイズ接点のコンダクタンス測定を行い,以下の結果を得た．

（１）逆方向バイアス p-n 接合のときに接点は長く引き伸ばされ，コンダクタンスは $10^{-5}G_0$ 程度の低い値に達する．他のバイアス条件では，多くの接点はあまり伸びずに破断する．

（２）Si 接点が伸長するとき，コンダクタンスの対数は接合距離 L の 2 次関数で変化する．このコンダクタンスの距離依存性は接点が disorder 構造であり局在伝導を示すことを示唆している．

５．発表（投稿）論文

Si-Si 接点の伝導特性に関する論文を投稿準備中．

酸化物ヘテロ界面における電気伝導特性

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１．　はじめに

The purpose of this collaboration project is to further the development of two-dimensional carrier systems in ultra-thin oxide films and epitaxial oxide heterostructures. Several oxide systems have been identified where carrier mobility is approaching 10,000 at liquid helium temperature and where carriers are confined in at least semi two-dimensional layers. Such systems are known to exist, for example, in ZnO heterostructures and in polar titanate heterointerfaces. While the development of two-dimensional electron systems is mainly of academic interest, e.g. for the observation of quantum Hall effect, the techniques and methods for fabricating suitable heterostructures are applicable to a wide range of novel electronic devices that make use of the functional properties of oxides. The key factors that determine the level of carrier confinement and carrier mobility in heterostructures are the level of crystallinity, i.e. the density of impurity-related defects and the presence of crystal growth defects. Another important aspect is the doping of oxide layers to achieve the desired level of conductivity. These challenges have all been addressed in developing p-type ZnO-based structures and oxide field-effect transistors. This collaborative project allowed our respective laboratories to exchange information and organize discussion seminars for the purpose of developing better oxide thin film growth techniques, with a particular focus on thin film growth chamber design, temperature control during crystal growth, and the monitoring of the thin film growth front by in situ and real time electron diffraction.

２．　研究経過

Work in our respective laboratories has proceeded on all planned fronts. A critical component of synthesizing high-quality oxide heterostructures is the functionality of the thin film growth chamber. The development effort has proceeded in the direction of developing more compact pulsed laser deposition systems in Kashiwa. The aim is to downsize the deposition system in order to increase throughput and to perform sample synthesis at a lower cost of equipment, materials, and energy. In particular, we are studying the effects of changing the temporal characteristics of the ablation laser pulse in order to perform thin film growth by laser ablation at lower laser fluence levels. This would allow us to use significantly cheaper and smaller lasers and therefore increase the number of samples that can be synthesized and ultimately characterized. Since the physical properties of oxide films are exceedingly sensitive to process parameter variations, it is always necessary to fabricate a large number of samples to find the optimal growth conditions. Being able to do this work much more quickly has a direct impact on developing novel oxide films and heterostructures. The Sendai group has further developed high-throughput sputter deposition systems for fabricating many samples in sequence. Extending the deposition techniques to other thin film growth methods will allow an expansion of the development of electronic materials beyond oxides. We are also continuing the development of laser heating techniques for thin film growth. Using a laser for sample heating has a number of advantages, including maintaining a clean vacuum even at very high growth temperatures, and allowing for rapid temperature changes. Temperature modulated growth of oxides has, for example, been the key to developing p-type ZnO thin films with dramatically improved crystallinity.

３．　研究成果

The specific projects that we have worked on during this year involved the development of laser heating. We have designed and constructed new optical solutions for delivering heating laser light into a chamber coaxially with the optical pyrometer. A hot mirror will be used to separate the high-power semiconductor laser light from the broadband infrared signal used for measuring the sample temperature. This heating design will allow a significant reduction of heating stage size and can be used to measure directly the temperature of the metal block that is used for sample mounting. This technique can therefore be used to obtain a more reliable temperature reading when the thin film surface temperature measurement is not possible due to the presence of combinatorial masks in the chamber or because the emissivity factor of the sample changes during film growth, as is common for non-transparent materials. This particular optics will be used for integrating compact semiconductor lasers in the 40W range with miniature thin film growth systems. The electron diffraction monitoring system development work has been an ongoing project for the past several years. Reflection high-energy electron diffraction (RHEED) is a standard technique for monitoring the surface morphology and growth rate of thin films. We have further developed this technique to allow for rapid electron beam scanning in order to monitor the growth of a film simultaneously at several points on the sample surface and to measure real-time rocking curves of a crystal surface. During this year we have continued the development of the diffraction monitoring software and have designed and tested new electron beam optics for achieving more efficient beam scanning.

４．　ま と め

We are grateful for the support that we have received for the continuation of collaborative research efforts between the Kashiwa and Sendai groups. The financial support provided by the joint use program has allowed us to exchange ideas and organize meetings to discuss thin film growth and develop new methods for growth control. This joint work has, in part, helped us in our respective research projects, developing low-dimensional oxide systems.

５．　発表（投稿）論文

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