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Fabrication of Planar Nano-gap Electrodes for Single Molecule Evaluation

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1. Introduction

Single molecule electronics [1] are expected to supersede silicon electronics beyond their limitations, therefore increasing number of scientists involve in synthesizing and measuring single molecule characteristics in order to establish the new paradigm of information processing devices 10-15 years from now. Many experimental demonstrations have been reported so far aiming for measuring the conduction characteristics of single molecule, however, all the experiments have not been able to ascertain the actual number of molecules and actual site of connection between molecules and electrodes, became of the very ragged structure of the electrode [2]. The results are merely derived from the two terminal I-V measurement, which represent indirect evidence of the characteristics. In order to ascertain “single molecule measurement”, a planar nano-gap electrode is essential, by which the molecule between the electrodes can be directly observable by AFM, as schematically shown in Fig. 1. The planar structure also avoids unsuitable deformation and resulting deviation of characteristics of the single molecules connected to the electrodes, as also depicted in Fig. 1. Relatively straight-forward way of fabricating the planar electrodes use CMP (Chemical Mechanical Polishing) to planarized the insulator/electrode structures [3], however, polishing speed variation across the wafer and “dishing” [4] prevent from reproducible fabrication. This paper reports on the advanced fabrication technology of planar nano-gap electrodes, which use wafer bonding technologies.

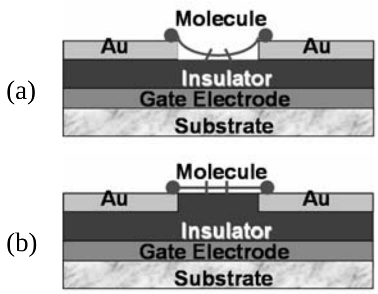

Fig. 1 Schematic illustration of molecule on electrodes. Step type (a) and flat type (b).

2. Experimental Procedures

Schematic cross section of the fabrication process of the planar nano-gap electrodes is shown in Fig. 2. A 50nm thick Ni layer was deposited on a Si (100) oriented 10ohm･cm wafer, followed by electrode pattern formation by electron beam lithography technology. Then, Au layers were evaporated to a thickness of 40nm, and lift-off process formed nano-gap gold electrodes. Plasma TEOS (tetra ethoxy silane) SiO_2 layers were deposited to a thickness of 300nm, followed by a Cu gate electrode layer formation (Fig. 2(a)). A 400µm thick pyrex glass substrate was anodically bonded on the electrode layer (Fig. 2(b)). Finally, the Si substrate and the Ni layer were removed by etching and the flat nano-electrode surface reveals (Fig. 2(c)).

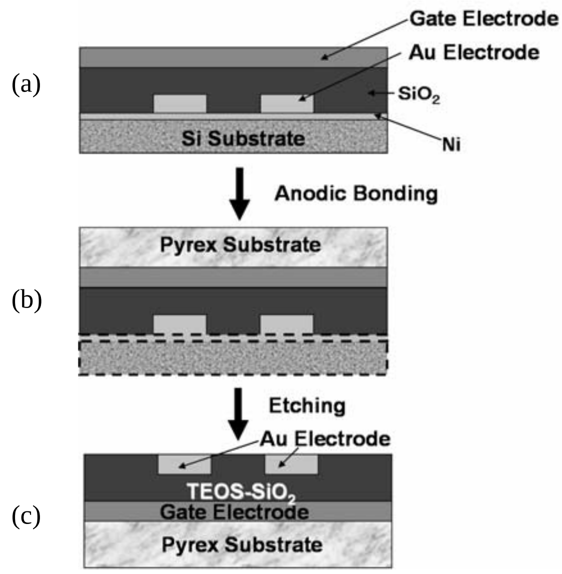

Fig. 2 Schematic cross section of the fabrication process.

3. Results and Discussion

An optical micrograph and an AFM image of the fabricated planar nano-gap electrode are show in Fig3. They clearly indicate that the surface raggedness and the step height of the electrode-insulator interface are small enough, in the order of nm, and that they almost fulfill the necessary requirements to place the single molecule and to measure their characteristics. In order to ascertain the flatness of the electrodes, surface raggedness through line A-A' in Fig. 3 was measured and the results are shown in Fig. 4. They depict that the step height between electrode and insulator is almost negligible and that the surface unevenness is ±2nm for a length of about 5μm. Since the diameter of a single molecule is around 1nm, and the length is around 10-20 nm, the surface flatness is almost suitable for single molecule measurement. The present electrode separation measures 200nm, however, combined with the 15nm gap fabrication technology shown in Fig. 5, a 10-20 nm gap electrode would be achievable. Further improvement of the planarization process would realize less than 1nm-flat nano-gap electrodes.

Insulation characteristics of the fabricated electrodes were evaluated and were in the order of 10^{12} ohm, which indicates that they are high enough for measuring conduction characteristics through single molecule.

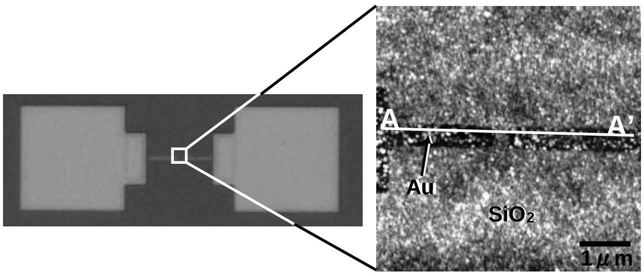

Fig. 3 Optical micrograph (left) and AFM image (right) of planar nano-gap electrodes.

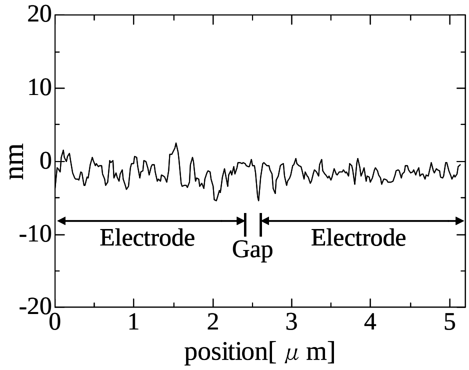

Fig. 4 AFM scan profile along the line A-A' in Fig. 3.

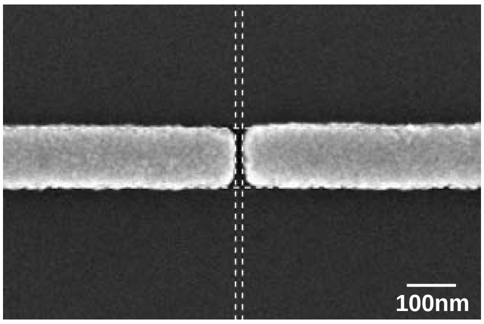

Fig. 5 SEM image of a 15nm gap electrodes fabricated by EB Lithography.

4. Conclusions

This paper described the planar nano-gap electrode fabrication technology by anode bonding. Currently, the surface raggedness measure about ±2nm, and further improvement of planarization process would realize nm flat electrodes for measuring single molecule characteristics. The planar nano-gap electrode will become the milestone for the new paradigm of information processing devices.

Acknowledgements

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References

[1] Y.Wada, H.Yamada, and K.Matsushige, "Prospects for molecular nanoelectronics", OYO BUTURI, Vol.70, No.12, p1395-1407 (2001-12)

[2] Saiful I. Khondaker and Zhen Yao, "Fabrication of nanometer-spaced electrodes using gold nanoparticle", Appl. Phys. Lett, vol.81, No.24, pp.4613-4615 (2002)

[3] Tomohiko Edura, et al., Fabrication of Micro-Gap Electrodes for Molecular Electronics, IEEEJ Trans. EIS, Vol.124, No.6, p1213-1218 (2004)

[4] Peter Singer, "Copper CMP Taking aim at Dishing", Semiconductor International (2004-10-1)