Extended Abstracts of the 20th (1988 International) Conference on Solid State Devices and Materials, Tokyo, 1988, pp. 239-242

Evidence of Resonant Tunneling in a-Si:H/a-$Si_{1-x}C_x$:H Superlattice Structures

Y.L. JIANG, H.L. HWANG, *C.E. NEBEL, and *G.H. BAUER

Department of Electrical Engineering, Tsing Hua University, Hsin-chu, Taiwan, China.

*Institut fuer Physikalische Elektronik, Universitat Stuttgart, Paffenwaldring 47, D-7000 Stuttgart-80, F. R. Germany.

a-Si:H/a-$Si_{1-x}C_x$:H superlattice structure films were fabricated by photo-CVD and GD-CVD. The blue shift of the optical bandgap and the PL peak was distinctly observed. The existence of quantum size effects in amorphous superlattice was demonstrated by the observation of resonant tunneling current through the three-barrier two-well structure and the multi-well structure.

1. INTRODUCTION

Ultra-thin amorphous silicon based multilayers would exhibit very unique properties as in the case of crystalline semiconductors only if they also possess the quantum size effects (QSE). It has been an ambiquity whether or not the QSE really exists in ultra-thin amorphous semiconductor multilayers. The staircase structure of interband optical transitions was only observed recently in differential optical absorption spectra.[1] The carrier confinement was confirmed from the photoluminescence quenching by electric field perpendicularly applied to the layers.[2] The most direct evidence was provided by measuring the I-V characteristics perpendicular to the layers. M. Hirose et al. studied the current transport across a a-Si:H/a-Si_3N_4:H double-barrier single-well structure and observed current bumps which are consistent with their WKB approximation analysis at 77K.[3] However, due to some unconfirmed causes, the current bumps were not really obvious and distinct.

In the present experiment, a-Si:H/a-$Si_{1-x}C_x$:H superlattice structure films were fabricated by photo chemical vapor deposition (photo-CVD) and glow discharge chemical vapor deposition (GD-CVD) methods. The multilayers structure had been investigated by X-ray diffraction and AES depth profile analyses.[4] The optical characteristics such as transmission, photothermal deflection spectroscopy (PDS) and photoluminescence (PL) were measured. By using the three-barrier two-well structure and multi-well structure , the current transport perpendicular to the multilayers were investigated.

2. EXPERIMENTS

The 25-80 period a-Si:H/a-$Si_{1-x}C_x$:H multilayers were fabricated by photo-CVD. The deposition process was programmed by a micro-computer which controlled the gas change, reactor pressure and the on-off of the mercury lamp. The samples that contain three-barrier two-well struture and multi-well structure were fabricated by GD-CVD. In order to obtain abrupt interfaces, the

reactor was purged and the murcury lamp or RF power was turned off at each step of the individual layer deposition.

The priodicity and the interface abruptness of the multilayers were confirmed by X-ray Bragg diffraction and Auger depth profiles, which are considered to be adequate to support the presence of the QSE.[4] Optical absorption data were determined from the conventional transmission spectroscopy and PDS at room temperature. The 17K PL were done with excitation at 4880 Å Ar^+ laser line. The resonant tunneling of electrons perpendicular to the multiple barrier structures was measured at 88K by using the sandwich configuration.

3. RESULTS and DISCUSSION

The optical bandgap are shown to be directly proportional to the inverse of the square of the layer thickness[4], and as shown in fig.1 , the peak position of the PL signals shifted to the higher energy when the well thickness was decreased. The distinct appearance of the 2.1eV peak(Figs. 1(b) & 1(d)) indicates that owing to the quantization effect, the tail states near the mobility edge are reduced to the staircase distribution, and the PL signals at the about 2.1eV are possiblely caused by the recombination from the staircase tail states below the conduction mobility edge to those above the valence mobility edge.

Measurements of transport properties vertical to the superlattice structure indicate that carrier transport in darkness is dominated by tunneling. If the energy levels arising from the "multiple" wells were resonantly aligned under the appropriate biased conditions, the transmittivity should be enhanced, and the current bumps should become more evident. By using this structure, we should be able to identify the QSE more de-

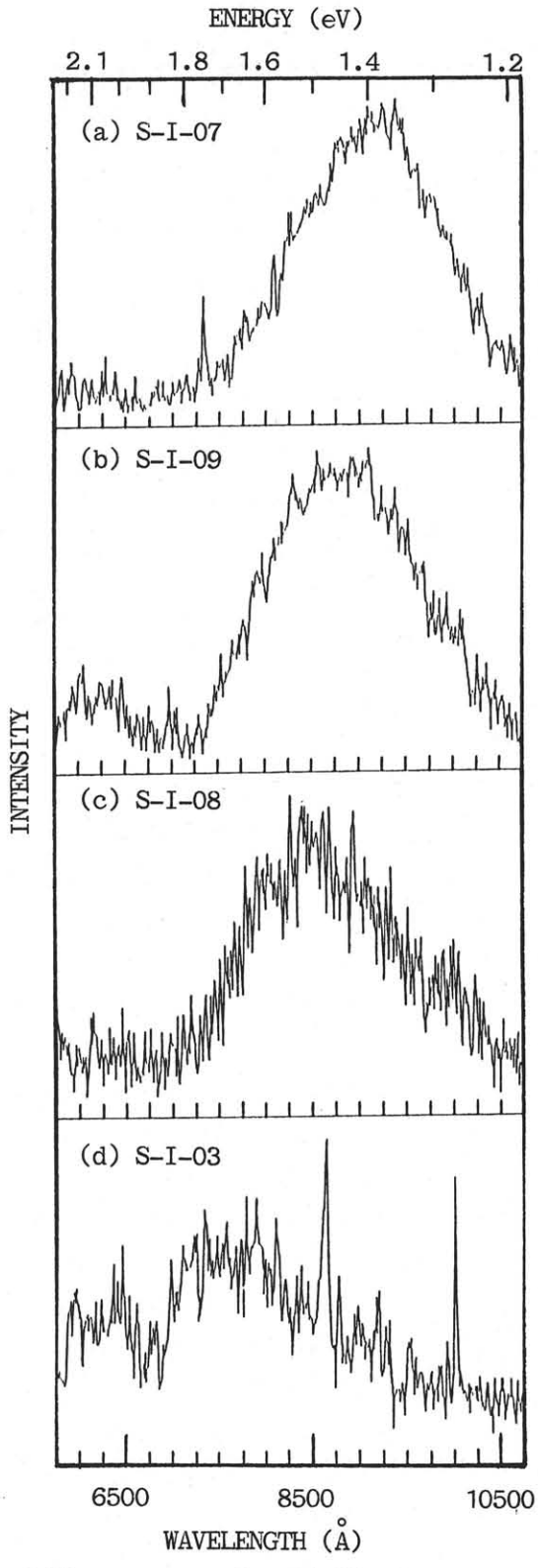

Fig.1 PL spectrum of a-Si:H/a-$Si_{1-x}C_x$:H superlattices. (a) sample S-I-07(30 layers, periodic layer thickness:12.3nm), (b)sample S-I-09(25 layers, periodic layer thickness: 6.8nm), (c) sample S-I-08(30 layers, periodic layer thickness:7.66nm), (d) sample S-I-03(80 layers, periodic layer thickness: 3.1nm).

finitely. Figs. 2-3 show the 88K I-V curves of the multilayers prepared by GD-CVD. The sample shown in Fig. 2 contains a three-barrier and two-well structure, and the energy level in the thinner well is higher than that of the thicker one. Under the appropriate biased conditions, the energy levels are lined up, and resonant tunneling of electrons should occur through the quantized states. Our results confirm this fact, and the current enhancement becomes much more distinct than that demonstrated in Hirose et al.[3] In other words, by adding one more barrier and well to the multilayer structure, (and by varying the well thickness), the resonant tunneling effect could be more pronounced. The possible fluctuations of the conduction band edge arising from the lack of long range order significantly blurs the quantized energy levels even if they are present;[3] this effect may have been overcome in our new structures. Furthermore, when more periods were added to the structure, the resonant tunneling of electrons should still prevail, and this was actually found to be the case in Fig. 3, in which there are twenty ~25 Å wells.

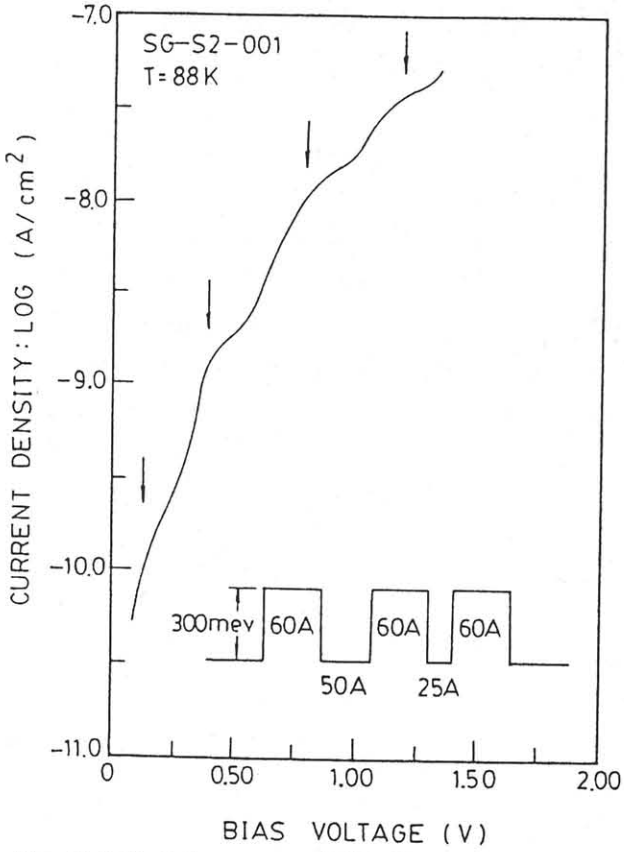

Fig.2 88K I-V curve of SG-S2-001.

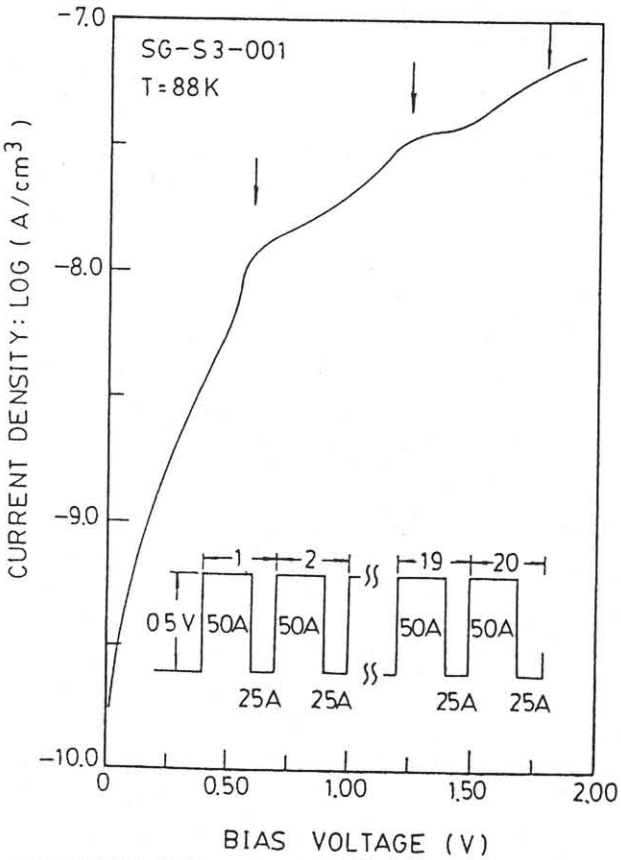

Fig.3 88K I-V curve of SG-S3-001 which consists of 20 periods.

4. CONCLUSIONS

The quantum size effects of a-Si:H/a-$Si_{1-x}C_x$:H multilayers prepared by photo-CVD and GD-CVD have been confirmed from their optical and electrical transport properties. The most direct evidence was obtained from the results of current transport perpendicular to the layers. By using the three-barrier two-well structure and multi-well structure , we obtained distinct current bumps to indicate the resonance tunneling of electrons in the superlattice structure, which provides the most undeniable evidence for the QSE to-date.

5. REFERENCES

1) K. Hattori, T. Mori, H. Okamoto and Y. Hamakawa; Phys. Rev. Lett. 60(9),825, 1988.

2) M. Hirose and S. Miyazaki; J. Non-Cryst. Solids 66(1,2), 327, 1984.

3) S. Miyazaki, Y. Ihara, and M. Hirose; Phys. Rev. Lett. 59(1), 125, 1987.

4) C. E. Nebel et al.; presented at the MRS spring metting, Reno, Nevada, U.S.A.,April 5-9,1988.