Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 74-75

Formation of Size- and Position-Controlled Nanometer Size Pt Dots on GaAs and InP Substrates by Pulsed Electrochemical Deposition

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1. Introduction

A promising approach for high-density integration of single-electron transistors and memories is to form size- and position-controlled metal nano-particles on suitable substrates at a high density, and utilize them for device fabrication.

The purpose of this paper is to show that nanometer-size Pt dots can be formed in a size- and position-controlled fashion on GaAs and InP substrates by combining our novel *in situ* electrochemical process with the electron beam (EB) lithography.

2. Experimental

The novel electrochemical process consisted of anodic etching of semiconductors followed by subsequent *in situ* cathodic deposition of metal in the same HCl-based electrolyte containing Pt ions. Figure 1 shows the setup of the process together with the pulse-waveforms applied to the substrate. The potential of the semiconductor electrode against the reference electrode was controlled by a potentiostat with a pulser. Use of the pulsed mode instead of the d.c. mode was found powerful for accurate control of the etching and the deposition thickness by the number of pulses. We have already shown that the pulsed electrochemical process can produce high Schottky barrier heights for n-GaAs (1.1eV[1]) and n-InP (0.9eV[2]).

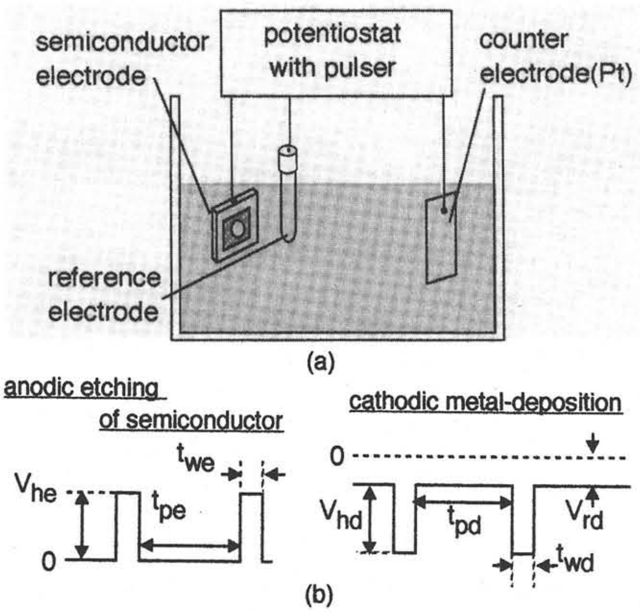

Fig. 1. (a) Schematic setup of *in situ* electrochemical process and (b) pulse waveforms used for *in situ* etching and deposition.

3. Results and Discussions

Surface morphology of Pt deposited substrates

Figure 2 shows the Pt-deposited surface on unpatterned n-GaAs and n-InP by the pulsed electrochemical process. In the initial stages of deposition, nanometer-sized Pt particles were formed on the substrates. Further deposition increased the number of particles, eventually leading to full surface coverage by Pt nano-particles. Figure 3 compares the

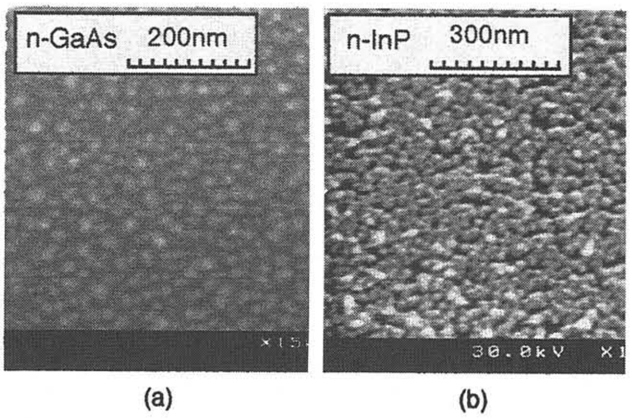

Fig. 2. SEM images of Pt-deposited (a) n-GaAs and (b) n-InP surfaces by pulsed electrochemical process.

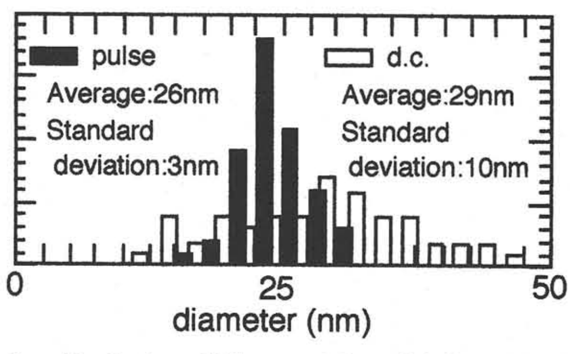

Fig. 3. Distribution of diameter of Pt particle formed by d.c. mode and by pulsed mode.

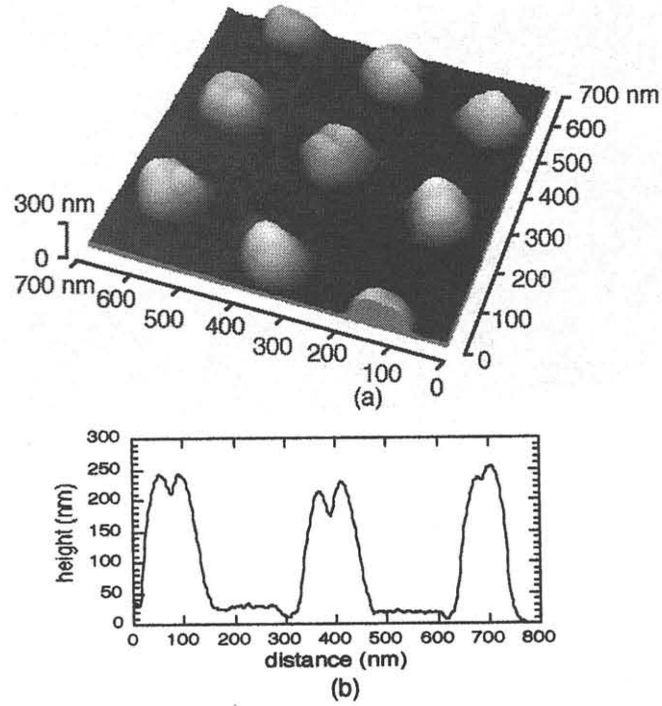

Fig. 4. (a) AFM image and (b) its sectional profile of Pt dot array with a pitch of 300nm on patterned n-GaAs substrate.

distribution of Pt particle diameter formed by the d.c. mode and by the pulsed mode. The pulsed mode produced smaller and more uniform Pt particles. Furthermore, the particle diameter and its distribution became smaller and more uniform with smaller pulse widths and longer pulse periods. This result shows that the size distribution is basically determined by supply of metal-ion species at the semiconductor/electrolyte interface, and that the particle size can be controlled by height (V_{hd}), width (t_{wd}) and period (t_{pd}) of the applied pulses.

Fabrication of Pt dot array on n-GaAs

In order to selectively deposit dots at desired positions, windows were patterned on GaAs and InP substrates by standard EB lithography before the electrochemical Pt deposition. In Figs. 4 and 5, the results for arrays of circular windows on GaAs sbstrates with a pitch of 200-300nm are shown. As seen in Fig. 4, Pt dots were selectively formed only within the opened windows, thereby realizing precise dot-position control. Furthermore, it was also found that Pt dots were formed at the center of each open window not touching the window periphery initially, as seen in Fig. 5. In this case, the size of Pt dots increased in proportion to the number of the applied pulses, and the smallest particles with diameter of 20nm was obtained by applying one pulse. Further size reduction seems to be possible by optimization.

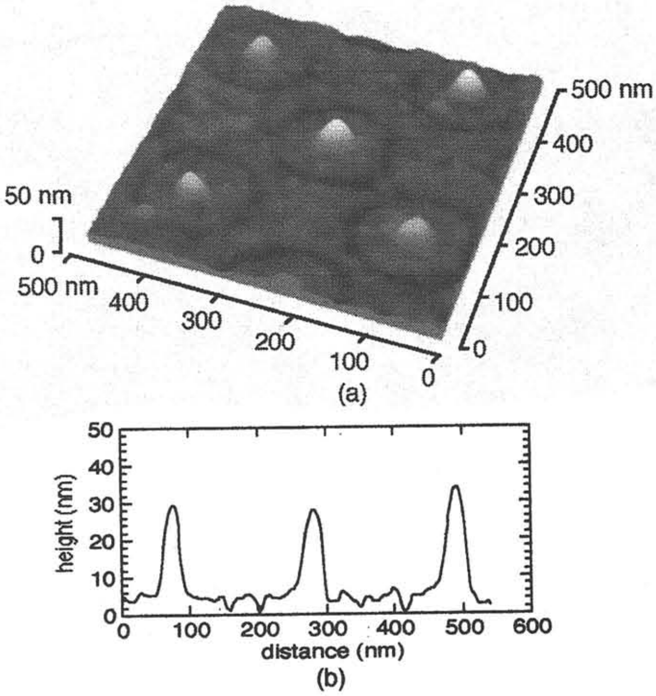

Fig. 5. (a) AFM image and (b) its sectional profile of Pt dot array with a pitch of 200nm formed at the center of each open window on n-GaAs.

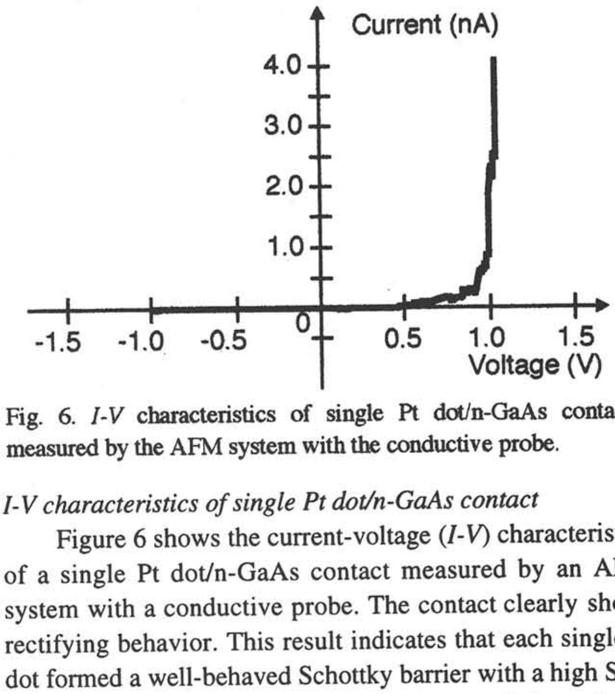

Fig. 6. *I-V* characteristics of single Pt dot/n-GaAs contact measured by the AFM system with the conductive probe.

I-V characteristics of single Pt dot/n-GaAs contact

Figure 6 shows the current-voltage (*I-V*) characteristics of a single Pt dot/n-GaAs contact measured by an AFM system with a conductive probe. The contact clearly shows rectifying behavior. This result indicates that each single Pt dot formed a well-behaved Schottky barrier with a high SBH ($\simeq$ 1.0eV) and very low leakage currents on n-GaAs surfaces. Thus, this electrochemical process is promising for fabrication of metal Schottky dot arrays for single-electron and quantum devices.

References

1) N-J. Wu, T. Hashizume and H. Hasegawa: Jpn. J. Appl. Phys. **33**(1994)936

2) T. Sato, S. Uno, T. Hashizume and H. Hasegawa: Jpn. J. Appl. Phys. **36**(1997)1811