Controllable Growth and Unexpected Effects of Ge Nanocrystals

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Supporting information

1. TEM evidences

Figures S1 shows the TEM bright-field images of the Au/Ge bilayer films annealed at (a) 120 °C for 50 min, (b) 120 °C for 60 min, (c) 120 °C for 70 min, (d) 150 °C for 50 min, (e) 150 °C for 60 min, and (f) 150 °C for 70 min. It can be seen that these nanofractal structures are present throughout the surface of the annealed films. The experimental investigations from these TEM images indicate that when the annealing time (temperature) is short (low), for example, the films annealed at 120 °C and 150 °C for 50 min, a few separated nanofractal patterns show in the films (see Figure S1 a and d, respectively). With increasing annealing time and temperature, the nanofractals with dense branches extend to the whole films (see Figure S1 c and e). The experimental evidence reveals that these nanofractals are reproducible and in fact change considerable as a function of the annealing temperature

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Figure S1. TEM bright-field images of Au/Ge bilayer films annealed at (a) 120 °C for 50 min, (b) 120 °C for 60 min, (c) 120 °C for 70 min, (d) 150 °C for 50 min, (e) 150 °C for 60 min, and (f) 150 °C for 70 min.
2. V-I curve for the films annealed at 100 °C for 60 min

Figures S2 shows the V-I curve of the Au/Ge bilayer films annealed at 100 °C for 60 minutes. It can be seen that the V-I behavior of the films shows the conventional ohmic characteristics, namely, it did not show the nonlinear V-I behavior.

*Figure S2. V-I curve of the Au/Ge bilayer films annealed at 100 °C for 60 min.*
3. Nonlinear V-I behavior

This nonlinear V-I behavior could be associated with Schottky contacts. After the amorphous Ge crystallization in the Au/Ge bilayer films, the nanofractal patterns formed by polycrystalline Ge grains show a self-similar morphology, so the Au layer did not form a homogeneous film. The whole film could be considered to be composed of linked metal islands and a series of the tunneling junctions, and the annealed film is composed of the series connections of the metal fractions and \( N \) tunneling junctions. Assuming that the resistance of these junctions before and after the breakdown are constant \( r_1 \) and \( r_2 \) respectively, and \( r_1 > r_2 \), and if the external voltage is not too high, the distribution of the breakdown voltage could be approximated to a Gauss function. So the resistance of the film should be:

\[
R(V) = r_0 + r_1 NA \int_{V}^{\infty} f(u) du + r_2 NA \int_{0}^{V} f(u) du \tag{1}
\]

with

\[
f(u) = \exp[-(u - u_0)^2 / 2\sigma^2]; \quad A = \int_{0}^{\infty} f(u) du
\]

where \( r_0 \) is the sum of all the metal fraction resistances. \( A \) is a normalization constant, \( u_0 \) is the most probable distribution breakdown voltage, and \( \sigma \) is the root-mean-square deviation of the integral variables. The formula (1) can be simplified to:

\[
R(V) = R_0 - R_1 A \int_{0}^{V} f(u) du \tag{2}
\]

where \( R_0 \) is the film resistance without the external voltage, that is, when \( V = 0 \), \( R_0 \) is the differential resistance \( (dV/dI)_V = 0 \). \( R_0 - R_1 \) is approximately equal to the film resistance when all the tunneling junctions are the breakdown, that is, it is the film resistance of \( V \to \infty \). Then the V-I behavior of the films with nanofractals should be:

\[
I = \frac{V}{R(V)} \tag{3}
\]
According to the formulae (2) and (3), we can insight into the physical significance from above
formula. Some tunneling junction fractions will be the breakdown in succession with increasing
measuring voltage, and $R (V)$ will decrease gradually, which will cause the nonlinear V-I behavior of
the films.