Anomalous effective viscoelastic, thermoelastic, dielectric, and piezoelectric properties of negative-stiffness composites and their stability

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Ferroelastic materials exhibit two different shapes of energy landscape; one contains only a single energy minimum, and the other two energy minima. From high temperature to low temperature, the solid-solid phase transition of the ferroelastic materials changes their microstructures from high to low symmetrical ones. The single energy minimum before transformation becomes a energy maximum point, hence it possesses negative stiffness because modulus is a second derivative of the energy landscape. Combining the ferroelastic inclusion in regular elastic materials to form composite materials, one would observe their unexpected overall properties, such as extremely large or small effective damping, viscoelastic moduli, thermal expansion coefficients, piezoelectric constants and dielectric constants. In this paper, the finite element method was adopted to numerically calculate the effective properties of the composites under the coupled-field effects. The numerical method can be considered as converting the original continuum-level description of the problem into a discretized version. The stability of the composite systems was calculated in consistence with Lyapunov’s stability theorem. It is found that the extreme properties of the negative-stiffness composite materials may be stabilized by the coupled-field effects, also known as multi-physics effects.
Master equation approach to transient quantum transport in nanostructures incorporating initial correlations

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Quantum transport incorporating initial correlations in nanostructures is a long-standing problem in mesoscopic physics. In the past two decades, investigations of quantum transport have been mainly focused on steady-state phenomena, where initial correlations are not essential due to memory loss. Recent experimental developments allow one to measure transient quantum transport in various nano and quantum devices. In the transient transport regime, initial correlations could induce different transport effects. In this paper, using the exact master equation approach we developed \cite{1,2,3}, we attempt to address the transient quantum transport incorporating initial correlations.

We derive for the first time the exact master equation incorporating initial system-environment correlations for a large class of electronic nanostructured systems. A new quantum transport theory incorporating initial system-environment correlations is naturally established with the exact master equation. We also find that the initial correlations only change the fluctuation dynamics of the device system, while the dissipation dynamics remains the same as in the case of initially uncorrelated systems.

We apply the theory to the single electron transistor in which is central island is a nano-scale quantum dot and the source and the drain (the leads) are modeled by a tight-binding structure. By calculate the dynamics of the electron occupation inside the dot and the transient transport current passing through the dot with an initially system-lead separated state and an initially system-lead correlated state, we find that initial correlation effects are significant in the transient regime, and they cannot be ignored in the steady-state limit if the device system contains localized states. Besides, when the localized states occur, the device system cannot approach equilibrium with the leads, and the initial system-lead correlation effects become significant.

References:

Global Oct4 target gene analysis reveals novel downstream PTEN and TNC genes required for drug-resistance and metastasis in lung cancer

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Oct4, encoded by POU5F1, is one of the key transcription factors for maintaining pluripotency of embryonic stem cells (ESCs). Although the genome-wide binding profile of Oct4 in ESCs has been reported, little is known about those in somatic cancer cells or tumor-initiating cells (TICs). To explore the underlying mechanism of Oct4 in driving somatic cancer into TIC-like states, we conducted chromatin-immunoprecipitation sequencing (ChIP-seq) to build the genome-wide Oct4 binding profile in A549 lung adenocarcinoma cells. Our results demonstrated that Oct4 occupied at promoter and enhancer regions of genes involved in tumorigenesis pathways, such as cellular movement, cellular growth and proliferation, cell death and survival, and development control. In addition, ChIP-seq analysis revealed novel Oct4-binding motifs in A549 lung adenocarcinoma cells which overlapped with DNA elements for Sp1 transcription factor. Validation of ChIP-seq analysis showed that Oct4 suppressed the expression of tumor suppressor genes, such as PTEN leading to drug resistance, or transactivated oncogenes, such as TNC leading to cancer invasion and metastasis. Our study also dissects the mechanism of Oct4 differential regulation on downstream genes. In the context of PTEN promoter, Sp1 serves as a platform for Oct4 binding and thus Oct4 recruits histone deacetylases HDAC1/2 complex to the PTEN promoter. In contrast, Oct4 transactivates TNC expression in a Sp1-independent manner (Figure 1). In clinical study, we found an inverse correlation between Oct4 and PTEN protein expression in lung cancer, while patients with high Oct4 expression showed concordantly increased TNC (Figure 2A). Notably, lung cancer patients with high expression of Oct4 and TNC and low expression of PTEN showed worse progression-free survival compared to patients with normal expression of the corresponding proteins (Figure 2B). Our study provides compelling evidence from lung cells, animal and clinical studies that Oct4-driven transcriptional program promotes drug-resistance and metastasis through PTEN and TNC, respectively.
Figure 1. Working models of differential targeting of Oct4, Sp1 and HDAC1/2 complex at PTEN and TNC promoters. Oct4 cooperates with Sp1 and HDAC1/2 complex to suppress PTEN expression while Oct4 can transactivate TNC expression independent of Sp1.

Figure 2. High Oct4 protein coincides with low PTEN and high TNC levels and poor progression-free survival of lung cancer patients. (A) Representative immunohistochemistry images of Oct4, PTEN and TNC proteins in tumor specimen of lung cancer patients. Oct4 positive immunoreactivity (+), PTEN negative immunoreactivity (–) and TNC positive immunoreactivity (+) were found in patient 1, whereas patient 2 shows a reverse pattern. Original magnification × 200. The insets are a higher magnification of the boxed areas. (B) Progression-free survival analyses indicated that patients with high Oct4 combined with both low PTEN and high TNC expression had significantly poorer survival than other patients. P-values for survival analyses were determined using log-rank test.

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Investigation of Barrier Property of Copper Manganese Alloy on Ruthenium

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In this study, we investigated the properties of CuMn/Ru stack as barrier materials for next-generation Cu interconnects. CuMn has been proposed as a self-forming barrier, which generates a thin barrier layer between CuMn and SiO2 after annealing at 450 °C [1-4]. However, to achieve high thermal stability and low resistivity, the annealing time, temperature and the concentration of Mn atoms in CuMn alloy processes are strictly specified [5]. Therefore, a structure of CuMn with an underlayer, such as Ru or Ta, is proposed in this study to further increase the thermal stability and process tolerance of the CuMn alloy.

For the experiment, barrier materials were grown on SiO2/p-Si (111) wafer with thermally oxidized SiO2 (100 nm). Barrier materials including Ru, Ta and CuMn were deposited by single-target sputtering method, and the thicknesses of Ru, Ta, and CuMn were controlled at 20, 30, and 150 nm respectively. The Mn concentration in CuMn alloy is from 0%-10%. Rapid thermal annealing (RTA) was applied to anneal the stack-layer structures for 30 min and the samples were then taken to thermal stability test.

Fig. 1 shows atomic distribution of CuMn/SiO2, CuMn/Ta/SiO2 and CuMn/Ru/SiO2 after 500 °C and 600 °C annealing, where the Mn concentration is 1% in CuMn alloy. The extension of Cu signal into the dielectric layer tells the barrier ability. We can observe when the annealing temperature was set at 500 °C, Cu atoms diffused into the dielectric layer in the CuMn/SiO2 and CuMn/Ta/SiO2 structures. In Fig. 1(d), the CuMn/Ru/SiO2 structure prevents the diffusion of Cu atoms even after annealing at 600 °C for 30 min, which agrees with TEM observations in Fig. 2. The Mn atoms blocked the diffusion paths in the Ru layer, and enhanced the barrier properties. With increasing Mn content, the thermal stability improved. Fig. 2 show the TEM pictures of CuMn/Ru/SiO2 with different Mn concentration. From Fig. 2(a), we knows that pure Ru is not able to prevent the diffusion of Cu and some Cu atoms was observed at the interface between Ru and SiO2. The barrier properties improved with increasing Mn content, as shown in Fig. 2(b), where the diffusion of Mn can be observed instead of Cu. The CuMn/Ru structure prevented the diffusion of Cu, but the CuMn/Ta structure did not when the Mn concentration is 1%. Therefore, with a Ru layer, the amount of Mn in CuMn can be lower than that with a Ta layer. The number of diffusion paths in the Ru layer is lower than that in the Ta layer, thus only a few amount of Mn content can still fully block the path in Ru.

These results indicate that with an underlayer of Ru, the tolerance in Mn concentration become higher. The decrease in Mn content leads to a decrease in the resistance of the metal line, which is beneficial for the interconnect requirement and sequential electroplating processes. In conclusion, the decrease in the Mn content not only increases the conductance of the metal line but also reduces the number of excess Mn atoms in Cu after heat treatment. Thus, the CuMn/Ru/SiO2 structure enhances not only the electrical properties but also adhesion and the barrier properties.
Figure 1. SIMS compositional depth profiles of (a) and (b) CuMn/SiO2, (c) and (d) CuMn/Ta/SiO2, and (e) and (f) CuMn/Ru/SiO2 with 1% Mn concentration after RTA process.

Figure 2. Cross-sectional TEM images of (a) Cu, (b) Cu–1 at.% Mn/Ru, (c) Cu–5 at.% Mn/Ru, and (d) Cu–10 at.% Mn/Ru samples after 500 °C RTA process.

Reference:


