

# THE FORMATION OF CUPPER TRANSITION NANO-LAYER IN POLYTETRAFLUOROETHYLENE SURFACE BY MEANS OF ION BEAM ASSISTING DEPOSITION

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The deposition of Cu on polytetrafluoroethylene surface assisted by the Ar ion beam with the temperature of 1 keV is investigated numerically. Ar ions provide the kinematic mixing of Cu atoms and atoms of substrate forming the connecting 10 nm layer of mixed material. This layer can ensure a good adhesion of Cu films deposited on polytetrafluoroethylene.

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## INTRODUCTION

The use of flexible circuits has become quite widespread because of their low cost, ease of assembly in interconnection systems, and the low volumes that they occupy [1]. Flexible circuits are most commonly used in board-to-board, board-to-chip, and chip-to-chip connections in packages having limited space and stacked rigid boards, thus requiring three-dimensional connections. Flexible circuits are largely used in portable electronic products, such as notebook, mobile phone, personal digital assistant, etc.

One of the applications for flexible circuits is high-frequency circuit film, which is a printed circuit board base material for high and very high frequencies. The material consists only of polytetrafluoroethylene (PTFE) and copper. Key point of this technology is the very high bond strength between the copper layer and the PTFE. Such bonding can be created due to transition layer, which is essentially the mixed material of PTFE and Cu atoms, implanted into the surface.

In this work, the numerical simulations are used to investigate the possibilities to create the transition layer by using ion beam assisted deposition technological process [2]. TRIDYN program [3] simulates co-bombardment of PTFE surface with low-energy Cu atoms and high-energy Ar ions. The results are used to study the dynamics of transition layer and factors, which affect the shape of the layer.

## NUMERICAL SIMULATIONS

To simulate ion beam assisted deposition, the Monte-Carlo program TRIDYN was used. It takes target changes in the composition caused by the incident projectiles into account and allows investigation of the fluence dependent effects, like change of the surface elemental composition and corresponding depth profiles, partial sputtering yields and reflection coefficients. As interaction potential, the C-Kr potential was used. The heat of sublimation was chosen to calculate the surface binding energy using model 3 as described in [4].

The program does not take into account chemical composition of the surface. Instead, only change in elemental composition of the surface caused by the sputtering and implantation is considered. Since the initial elemental composition of the PTFE consists of C and F with stoichiometric ratio of 1:3, this data is used as initial input. The target is homogeneous at the beginning, but its

composition varied by appearance of the Cu atoms on top of the surface and their collisional transport in the depth. The code does not take into account Ar implantation; instead, one assumes its immediate outgassing. According to model, used for the simulation, the role of the Ar ions is only to initiate collisional cascades causing the transport and atomic mixing of other elements.

In simulations, the PTFE surface was exposed to the mixed particle flux. Low energy Cu metal atoms are seeded with energetic gaseous Ar ions. The deposition is simulated by Cu projectiles with energy of 10 eV. Simulations show that the reflection coefficient of Cu is zero, i.e. 100% of particles are deposited on the surface. The energy of the assisted Ar ion beam has a Maxwellian distribution with the temperature of 1 keV. Because of the nature of the Monte-Carlo approach, each pseudo-projectile is attributed to certain fluence. In simulations, the total number of pseudo-projectiles is  $5 \cdot 10^5$ , each one carries the fluence of  $8 \cdot 10^{11} \text{cm}^{-2}$ , resulting in the total fluence of  $4 \cdot 10^{17} \text{cm}^{-2}$ .

## RESULTS AND DISCUSSION

The numerical study is focused on formation of the transition layer, which should connect the deposited Cu film and PTFE surface. High flux of Cu atoms is usually created by magnetron sputtering and, therefore, its typical energy is in the range of few eV. They reach the surface and are deposited, but generally, there is essentially no penetration in the depth below the surface. The transition between the surface and coating is sharp, which leads to low adhesion properties. The addition of the energetic Ar ion beam should diffuse the transition by recoiling Cu atoms deeper under the surface.

Typical evolution of the transition layer created by ion beam assisted deposition is shown in Fig.1. Initial penetration of Cu atoms under the surface is rather low; the concentration drops sharply at the depth  $>1$  nm. At fluence  $\approx 1 \cdot 10^{17} \text{cm}^{-2}$  the profile provides deeper and smoother transition between the surface (100% of Cu atoms) and the depth (at 8 nm the relative concentration of Cu atoms is 10%). At fluence of  $4 \cdot 10^{17} \text{cm}^{-2}$ , the width of the profile increases up to 10% of Cu atoms at the depth of 10 nm and total depth of 15 nm for the recoiled Cu atoms.

Further increase of the fluence does not affect the elemental profile, which becomes steady-state. Maximal depth of penetration for the Cu recoils is limited by maximal energy, which can be transferred through the

collision with Ar ion. The sputtering should also be considered as a limiting factor: it limits the number of Cu atoms on the surface and also decreases the depth of the Cu profile under the surface due to etching. Steady-state profile is fluence independent, which is useful for the technology. During exposition of the PTFE surface to the particle flux, the measurement of the exact fluence should be difficult task. It is recommended to overexpose the surface and, therefore, to obtain well predictable steady-state profile.

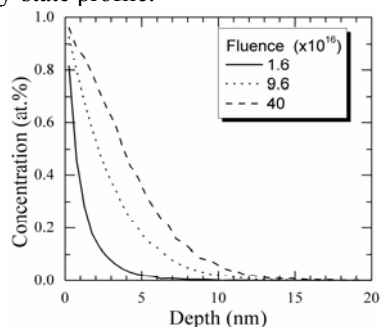


Fig.1. The evolution of the Cu profile in the PTFE surface exposed to flux containing 80% of Cu atoms with energy 10 eV and 20% of Ar ions with temperature of 1 keV. The fluence dependent evolution is calculated with TRIDYN

One can vary the parameters of the ion beam assisted deposition and obtain different profiles. Typically, the easiest way to influence the profile is by variation of Ar ion fraction in the total flux of particles. TRIDYN simulations have been performed to calculate the steady-state profiles of Cu atoms in PTFE surface. The results of simulations are shown in Fig.2.

At 10% of Ar ion fraction in total incident flux, the deposition of Cu layer is not compensated by sputtering with Ar ion beam. As the result, the PTFE surface is covered with layer. In Fig.2, the shape of profile for Ar ion fraction of 10% is stable; however, the simulations show that whole profile moves away from the surface due to Cu deposition, preserving its shape. During the formation of the transition, the growing Cu layer becomes a barrier between Cu recoils travelling from top of the surface deeper into PTFE surface. The resulting effect is lower number of recoiled Cu atoms and shorter depth of the transition layer: 10% of Cu concentration is already reached at 7 nm.

Increasing the Ar ion fraction in the total flux up to 30%, one can see that the transition layer becomes shorter. Due to higher Ar fraction, the surface together with deposited Cu layer is intensively sputtered. The balance between profile formation and surface erosion is shifted toward the erosion factor. Therefore, the transition layer

does not have enough Cu atoms to be formed. The concentration of Cu on surface is  $\approx 70\%$ ; 10% of Cu concentration is already reached at the depth of 5 nm.

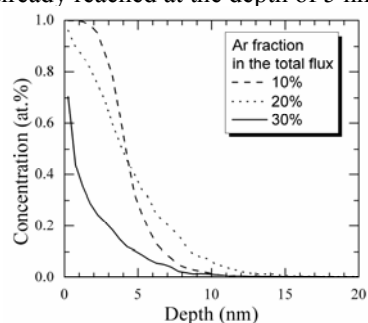


Fig.2. The steady-state Cu profiles in PTFE surface calculated for 10, 20 and 30% of Ar ion fraction in total incident flux

One can see that the deepest and smoothest profile of Cu atoms in the surface is created at 20% of Ar ion fraction in the total flux. It provides also 100% of Cu atoms on top of surface for a better adhesion.

## CONCLUSIONS

In this work, the formation of transition layer, which connects PTFE surface and Cu deposited layer had been studied by means of numerical simulations. The layer has been created by means of ion beam assisted deposition; the surface has been exposed to the flux of low-energy Cu atoms in combination with high-energy Ar ions. It has been shown that the layer is developed until the profile of the layer reaches stable shape either in steady-state or in regime of Cu deposition. By variation of the Ar ion fraction in the total flux, one can optimize the shape of the steady-state.

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## ФОРМИРОВАНИЕ МЕДНОГО ПЕРЕХОДНОГО НАНОСЛОЯ В ПОВЕРХНОСТИ ПОЛИТЕТРАФТОРЭТИЛЕНА СРЕДСТВАМИ ИОННО-СТИМУЛИРОВАННОГО ОСАЖДЕНИЯ

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Осаждение медного покрытия на поверхность политетрафторэтилена, стимулированное пучком ионов аргона с температурой 1 кэВ, изучалось методами численного моделирования. Ионы аргона обеспечивали смешивание атомов меди и поверхности, что позволило сформировать переходной слой шириной 10 нм. Такой слой может обеспечить хорошие адгезионные свойства металлической пленки, осажденной на поверхность политетрафторэтилена.

## ФОРМУВАННЯ МІДНОГО ПЕРЕХІДНОГО НАНОШАРУ В ПОВЕРХНІ ПОЛІТЕТРАФТОРЕТИЛЕНУ ЗАСОБАМИ ІОННО-СТИМУЛЬОВАНОГО ОСАДЖЕННЯ

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Осадження мідного покриття на поверхню політетрафторетилену, стимульоване пучком іонів аргону з температурою 1 кеВ, вивчалось методами чисельного моделювання. Іони аргону забезпечували змішування атомів міді і поверхні, що дозволило сформувати перехідний шар шириною 10 нм. Такий шар може забезпечити гарні адгезійні властивості металевої плівки, обложеної на поверхню політетрафторетилену.