NANOCOMPOSITE Ta-,Ti-SiN THIN FILMS: SYNTHESIS, PROPERTIES, AND APPLICATIONS IN HIGH TEMPERATURE ELECTRONICS

A.V. Kuchuk, V.P. Kladko, and A. Piotrowska[1]
V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine,
Pr. Nauky 41, 03028 Kyiv, Ukraine
[1]Institute of Electron Technology, Al. Lotnikow 32/46, 02-668 Warsaw, Poland
E-mail: kuchuk@isp.kiev.ua

Studies of the thin films of the type transition metal (Ta, Ti, W, Mo)-silicon-nitrogen have both scientifically interesting and practically useful [1-3]. A major interest has an application in the areas of aerospace, automobile, high temperature/power electronics, micro-electro-mechanics etc. The exceptional combination of properties, like a high melting point, good chemical stability, high electric conductivity, excellent diffusion barrier performance and hardness, makes them a widely used. However, those properties depending on many factors: a) fabrication technologies; b) chemical composition; c) structure-property relationships; d) post-deposition treatment etc. Therefore, in this work, we have investigated the effect of deposition parameters and post-deposition heat treatment on the material properties, and performance of Ta(Ti)-Si-N diffusion barriers in Au-based metallization of GaAs or GaN.

Binary Ta-,Ti-Si and ternary Ta-,Ti-SiN thin films were prepared by reactive RF (13,56 MHz) magnetron sputtering of Ta_5Si_3 (P = 200 W) and Ti_5Si_3 (P = 450 W) targets, in a pure Ar and various Ar/N_2 gaseous mixture, respectively. To determine the properties of investigated films, structures of the type Ta-,Ti-SiN/GaAs(GaN) and with Au-overlayer was prepared. In order to characterize the thermal stability, the samples were annealed up to $1000^{o}C$ for 3-5 min. in Ar ambient. The chemical and phase composition, electrical resistivity, mechanical stress, microstructure, surface morphology as well as diffusion barrier performances have been investigated using four-point probe sheet resistance measurements, stress measurement optical system, X-ray diffraction (XRD), secondary ion mass spectrometry (SIMS), Rutherford backscattering spectrometry (RBS), transmission electron-, and atomic force- microscopy (TEM, AFM).

For reactive sputtering of Ta-,Ti-SiN thin films, increasing of N_2/Ar flow ratio from 0 to 10%, results in increases of the N concentration into the films, electrical resistivity and change of mechanical stress (Table) [4]. These effects may be explained by incorporation of reactive nitrogen into the film during the sputtering process, and change of films microstructure. Indeed, all Ta-,Ti-Si films in the as-deposited state, exhibit broad X-ray diffraction “halo” characteristic of an amorphous material [5]. With increasing nitrogen content into the films, the position of the diffraction peak shifts to low angles and peak with at half maximum increase, indicating a structural differences in the amorphous state of the films [5]. These results indicating a change of the shot-range order of the Ta, Ti and Si atoms, due to the N suppression the reaction between Ta, Ti and Si atoms, by passivating the Ta-,Ti-silicides grain boundary with N atoms. Increase of the “degree of amorphism”, which agrees well with change of chemical composition and an increase of Ta-,Ti-SiN films resistivity, is result of silicon nitride SiN_x (nonconducting/amorphous) fraction rises into the films, and of transition metal nitride TaN_x or TiN_x (conducting/polycrystalline) decreases. Nanocomposite Ta-,Ti-SiN films may be viewed as a mixture of transition metal nitride imbedded in a silicon nitride amorphous matrix. This model explains the structure-property relationships and high temperature crystallization ($1000^{o}C$) of optimal Ta-,Ti-SiN thin-film diffusion barriers [6].

As shown in Fig. 1 and 2, the optimal amorphous Ta-,Ti-SiN diffusion barriers have excellent thermal stability (up to $800^{o}C$) preventing the metallurgical interaction in $Au/Ti_{26}Si_{17}N_{57}/Au/Pd/GaN$ and $Au/Ta_{34}Si_{25}N_{41}/GaN$ contact structures.

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Figures:

Table. Chemical composition, electrical resistivity, mechanical stress and phase composition of reactively sputtered Ta-,Ti-SiN thin films, in dependences of nitrogen content in sputtering plasma

N_2/Ar %	Composition (at.%)		Resistivity (μΩcm)		Stress (GPa)		Structure (by XRD)
	Ta-Si-N	Ti-Si-N	Ta-SiN	Ti-SiN	TaSiN	TiSiN	
0	$Ta_{67}Si_{33}$	$Ti_{62}Si_{28}$	295	312	-1.0	-0.7	nanocrystalline
4	–	$Ti_{27}Si_{20}N_{53}$	–	1012	–	-1.3	amorphous
5	$Ta_{53}Si_{20}N_{27}$	–	359	–	-1.5	–	amorphous
8	$Ta_{40}Si_{24}N_{36}$	$Ti_{26}Si_{17}N_{57}$	416	7527	-1.1	-1.4	amorphous
10	$Ta_{34}Si_{25}N_{41}$	$Ti_{25}Si_{16}N_{59}$	810	26600	-1.1	-1.4	amorphous

Fig. 1. The 2 MeV He^+ RBS spectra from as-deposited and annealed up to 800°C (Ar/3min) contact structure p-GaN/Pd/Au/$Ti_{26}Si_{17}N_{57}$/Au.
Thickness of the films:
Pd - 20nm;
Au - 130nm;
$Ti_{26}Si_{17}N_{57}$ - 100nm;
Au-overlayer - 100nm.

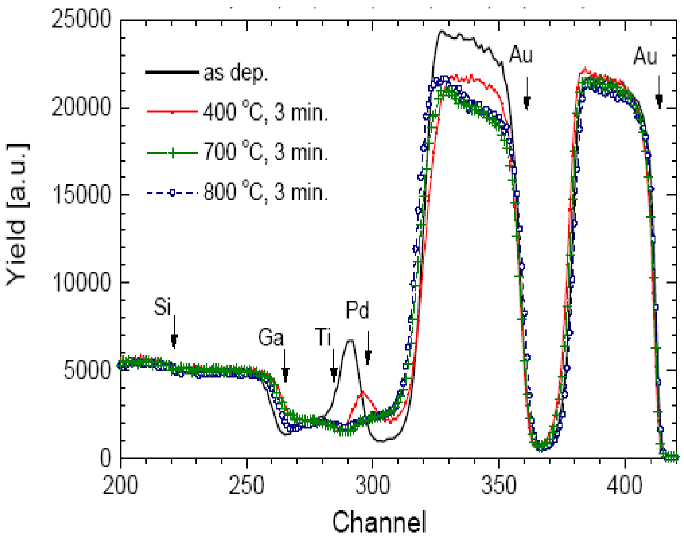

Fig. 2. Cross-sectional TEM micrographs of the GaAs/$Ta_{34}Si_{25}N_{41}$/Au samples: (a) as-deposited; (b) annealed at 800°C in Ar ambient for 5 min.