MORPHOLOGY OF Pb$_{1-x}$Eu$_x$Se EPITAXIAL FILM SURFACES AFTER PLASMA TREATMENT

S. P. Zimin,$^1$ E. S. Gorlachev,$^1$ M. N. Gerke,$^2$
S. V. Kutrovskaya,$^2$ and I. I. Amirov$^3$

UDC 539.21

The morphology of surfaces of Pb$_{1-x}$Eu$_x$Se epitaxial films on CaF$_2$/Si(111) substrates in the initial state and after treatment by high-density inductive Ar plasma in different regimes is investigated by the methods of atomic force microscopy. It is demonstrated that threading dislocations serve as cores for the formation of large bulges during sputtering of a semiconductor material. The influence of treatment regimes on the geometrical parameters of large bulges and characteristics of the surrounding nanorelief is revealed.

INTRODUCTION

Dry methods of metal, semiconductor, and dielectric treatment can significantly modify the surface, cause the formation of nanostructures, and change the mechanical, optical, and electric properties of the subsurface regions of the material. Sputtering of epitaxial layers in argon plasma is sensitive to the presence of threading dislocations. In [1] it was demonstrated that after treatment of n-PbTe/CaF$_2$/Si(111) epitaxial structures in high-density low-pressure inductive argon plasma, large bulges arise against the background of small bulges with density equal to that of triangular nanoterrace angles where threading dislocations emerge onto the surface. The triple Pb$_{1-x}$Eu$_x$Se solid solutions have received wide application in technology of IR optoelectronic devices. The formation of nanorelief on the lead selenide–europium selenide film surfaces seems to be important from the viewpoint of improvement of the parameters of these devices. The present work studies the morphology of surface epitaxial n-Pb$_{1-x}$Eu$_x$Se/CaF$_2$/Si(111) structures after treatment by a high-density inductive argon plasma in different technological regimes and compares the results obtained with the data available for the n-PbTe/CaF$_2$/Si(111) structures.

EXPERIMENT

The Pb$_{1-x}$Eu$_x$Se/CaF$_2$/Si(111) structures with \( x = 0.16 \) were prepared by Zogg et al. [2] by the method of molecular-beam epitaxy. The thickness of the buffer calcium fluoride layer was 4 nm. The CaF$_2$ layer was grown with a sedimentation rate of 0.1–0.2 Å/s for a substrate temperature of 650°C. The Pb$_{1-x}$Eu$_x$Se layers were deposited with a constant flow of 1 μm/h for a substrate temperature of 400°C using PbSe, Eu, and Se sources with temperatures of 1033, 733, and 463 K, respectively. The thickness of the PbSe–EuSe layers with n-type conductivity was 2.4 μm. The surface was treated in argon high-density inductive charged plasma (HDICP). Its HF power was 800 W at a frequency of 13.56 MHz. Bias HF powers of 300 and 400 W were applied to a substrate slider. The treatment time was 30 s. The sample surfaces were investigated by the methods of atomic force microscopy (AFM) using a SMENA (NT-MDT) atomic force microscope. AFM scanning of the surface was performed in air at room temperature in the semicontact regime.

---

$^1$P. G. Demidov Yaroslavl’ State University, e-mail: zimin@uniyar.ac.ru; $^2$Vladimir State University; $^3$Institute of Microelectronics and Informatics of the Russian Academy of Sciences. Translated from Izvestiya Vysshikh Uchebnykh Zavedenii, Fizika, No. 11, pp. 90–93, November, 2007.
RESULTS

Figure 1 shows a typical AFM scan of the examined film surface before plasma treatment. The surface of the initial Pb_{1-x}Eu_xSe epitaxial layers was rather smooth and has a characteristic nanorelief [2] in the form of slip triangular terraces with jogs 15–20 Å high. The occurrence of terraces is caused by epitaxial dislocation slip along the (100) directions because of the mechanical stresses arising during film cooling to room temperature due to different temperature expansion coefficients for the substrate and film [2]. Triangular pits were also observed where threading dislocations with density of ~1·10^{7} cm^{-2} emerged onto the surface.

During treatment in the argon plasma, the Pb_{1-x}Eu_xSe surface was nonuniformly sputtered; as a result, large bulges were formed against the background of smaller bulges. Figure 2 shows an AFM image of the lead selenide – europium selenide surface after plasma treatment with HF bias power of 300 W. Large bulges with heights up to 150 nm and lateral...