The plasma oxidation of a silicon surface in an inductive plasma generation reactor were studied using spectroscopic ellipsometry and atomic emission spectroscopy. The effect of inert gases on the formation kinetics of ultrathin SiO$_2$ films is discussed. The effect of intense oxidation of Si in the plasma formed by nominally pure helium was found. It is suggested that this effect is due to the photostimulated acceleration of the reaction at the silicon–oxide interface by the intrinsic optical emission from the helium plasma.

**Keywords:** silicon, plasma oxidation, silicon oxide, ellipsometry, atomic-emission spectroscopy.

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**INTRODUCTION**

Producing thin dielectric films by low-temperature methods is an important objective of modern microelectronics. Plasma chemical methods [1, 2] have a special place among many other low-temperature methods of producing thin and ultrathin films (particularly silicon oxide). However, it is often necessary to use complex combinations of process gases (e.g., a mixture of monosilane with ammonia or organosilicon compounds), which not only complicates the equipment, but can also adversely affect the quality of the films because of their inevitable pollution by chemical elements and radicals contained in the initial components of the working medium.

From this point of view, a promising method for producing thin oxide films is the direct oxidation of silicon in an oxygen plasma (or mixtures of oxygen and inert gases). The composition of the plasma-forming medium in this case may be the simplest. Films with a minimum amount of defects can be produced using modern facilities for inductive plasma generation, which produces a low-temperature homogeneous plasma with high ion density and a low electron temperature in a large volume at low operating pressure.

The aim of this study was to investigate the growth pattern and properties of films in plasma-forming media generated on the basis of mixtures of oxygen with various inert gases.

**HARDWARE. METHODS OF MEASUREMENT**

Plasma treatment was applied to standard silicon plates 100 mm in diameter with the \{100\} and \{111\} surface orientations of n-type and p-type conductivity with the doping level varying from $10^{15}$ to $10^{19}$–$10^{20}$ cm$^{-3}$. The plates were treated on a facility with a wide-aperture source with inductive generation [2]. The generator frequency was 13.56 MHz, and the power input to the discharge was 150–700 W. The substrate temperature was varied from room temperature to 200°C.

Film thickness was measured directly during film growth using an EM-70 built-in spectral ellipsometer ($\lambda = 380$–900 nm), and for prepared films using spectral and single-wave ellipsometry. In most of the cases
considered, the thickness of the films did not exceed 20–30 nm. To obtain quantitative data on the film thickness, it was necessary to solve some methodical problems. In the literature, there is a discussion of the hypothetical dependence of the optical parameters of SiO$_2$ films on their thickness (for $d \leq 30–40$ nm); in addition, it is assumed that the parameters of films produced by different methods [3–6] have a gradient nature. A comparison of ellipsometric data with the results of other measurements [current–voltage (CV) characteristics, infrared (IR) spectroscopy, and ultrasoft x-ray emission spectroscopy] suggests that the films grown in our case are similar in composition to the SiO$_2$ stoichiometric composition, and for them we therefore used a standard refractive index of 1.465 (light wavelength $\lambda = 550$ nm).

The plasma composition was determined by optical atomic emission spectroscopy using a Kvartz-2000 and a Kolibri-2 multichannel analyzers [7] in the wavelength range of 190–1100 nm, and the spectral lines were identified according to [8]. IR absorption spectra of the films were measured on an FT-801 Fourier spectrometer (500–4000 cm$^{-1}$). The CV characteristics of metal insulator semiconductor (MIS) structures based on the grown films were recorded on an E4980A (Agilent, USA) $LCR$ meter parameters in the frequency range 100 Hz to 2 MHz.

RESULTS AND DISCUSSION

Previously [9], we reported the results of studies of the formation kinetics and properties of silicon oxide films during treatment of its surface in an oxygen plasma. It has been established that the growth kinetics of oxide films is only slightly influenced by factors such as substrate temperature (20–200°C), the initial state of the surface, conductivity type, and the doping level of the substrate. This major factor determining the rate of growth of the films (besides the oxygen flux into the working chamber) is the RF power exciting the plasma. It seemed quite obvious that variations in the excitation power resulted in the corresponding changes in the concentration of the active (excited or ionized) oxygen in the gas phase, which determines the rate of oxidation.

In the literature [10–13], there are quite contradictory and not always clear indications on the influence of small additions of inert gases (from helium to xenon) on the parameters of plasma chemical processes. The results of studies carried out on facilities with different experimental conditions are often diametrically opposite in the kinetics of film formation and the final properties of films. In the present work, we also investigated the effect of the plasma composition (in mixtures of oxygen with argon, neon, and helium) on the formation kinetics and properties of oxide films.

Consideration of the oxidation of silicon in O$_2$–Ne and O$_2$–Ar mixtures showed no fundamental differences. Qualitatively, the picture is clear: a change in the ratio of the components of the gaseous medium leads to