REACTIVE CHARACTERISTICS OF OPTONEGATRON ELEMENTS ON THE BASE OF LOCAL POLYCRYSTALLINE SILICON FILMS

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Abstract. The capacitance-voltage characteristics of local polycrystalline silicon films were investigated in the frequency range 0,465-10 MHz. A transition in the character of reactive conductivity from capacitance to inductive behavior was discovered under influence the illumination the inductance transformed back into a capacitance and the negative resistance region disappeared from the current-voltage curve, consequently local polysilicon films are the optonegatron elements.

It is shown that inductivity phenomena in polycrystalline silicon films occur by processes of recharging of deep levels.

Optonegatronics, polycrystalline silicon films, reactive conductivity, inductivity, capacitance, deep level.

1. Introduction

Recently disordered structures have received much attention from designers of active devices as they offer an increase in functional possibilities per unit volume of electronic devices without an increase in the packing density of integrated circuits. Among the structures under consideration are amorphous semiconductors in which a phase transition takes place because of the action of different modes of excitation. This is followed by negative resistance and phase transition phenomena [1] by a transition of capacitive reactivity into inductive behavior [2] and possibility to form the optonegatron elements [3].

Of particular interest is the investigation of such phenomena in polycrystalline silicon (poly-Si) films, because silicon is the basic semiconductor material in microelectronics. Use of the technique of local growth of poly-Si films during the epitaxial formation of monocrystalline silicon [4] makes it possible to form elements with data processing circuits on the same chip. For example, according to [5], locally grown poly-Si films can be considered as distributed RC structures for integrated circuit filters. As shown in [6], locally grown poly-Si films exhibit a memory switching effect.

In this paper we report some inductive phenomena which were first observed in switching poli-Si films during capacitance-voltage measurements.

2. Experimental results

The poly-Si films (200μm×20μm) were formed on locally oxidized silicon-substrates of *p*-type conductivity with a resistivity of 10Ω·cm during the process of epitaxial growth of a 5μm monocrystalline film of *n*-type conductivity with a dopant concentration (phosphorus) of 10^{16} cm^{-3}. Epitaxial growth was performed in a heated (by high frequency power) vertical-type reactor using the high temperature (1200°C) chloride process. The waters were oxidized to obtain a pyrolytic oxide of thickness 3.5μm, and aluminum ohmic contacts were formed using photolithography and vacuum deposition techniques. The sample construction is presented on the Fig. 1.

The capacitance-voltage (C-V) characteristics were measured with an L2-7 impedance bridge at room temperature over the frequency range 0,465-10MHz using an ac signal of low voltage (25mV).

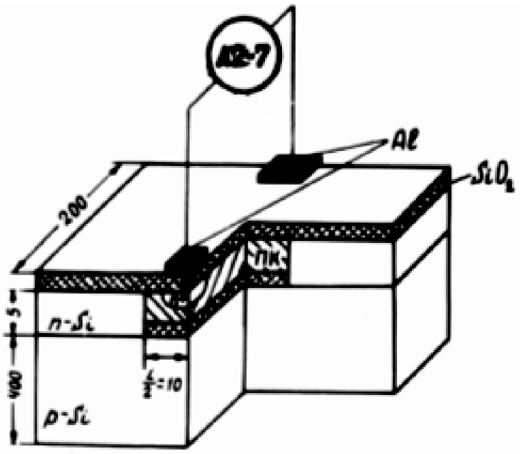

Fig. 1. Construction of the element on the base of a local poly-Si film

Typical C-V characteristics of poly-Si films in the OFF state at different frequencies of the ac signal are presented in fig.2,a. As can be seen, at definite voltage values for both bias polarities the capacitance changes from positive to negative, the phenomenon showing a purely inductive behaviour. With increasing frequency of the ac signal the voltage corresponding to this inversion of sign also increased. The capacitance of poly-Si films in the ON state was negative over the full frequency range (fig. 2,b).

From a comparison of the characteristics shown in fig. 2,a and fig. 3,a it appears that the sign inversion of the capacitance takes place at voltages near the threshold voltages of switching. The volt-ampere (I-V) characteristics of poly-Si films were measured on the waters by probes. When a microscope lamp with a power of 20 W was switched on, the negative resistance region disappeared from the I-V curve while the rest of the curve was almost unchanged (fig. 3,b). C-V measurements performed with and without illumination showed that under illumination the capacitance changed from negative to positive values simultaneously with the disappearance of the negative resistance region from the I-V curve.

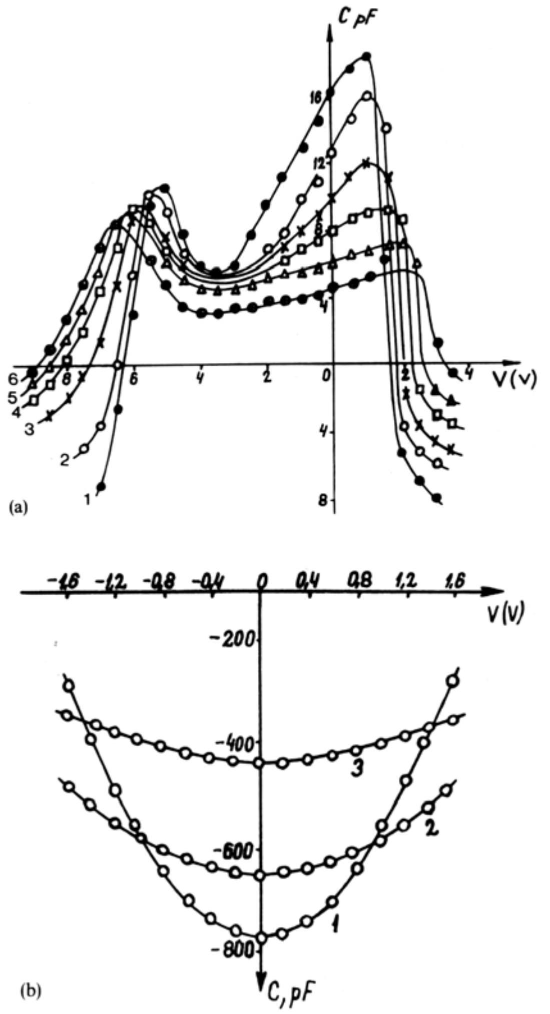

Fig. 2. Capacitance-voltage characteristics of a poly-Si film at various frequencies: (a) OFF state (curve 1 - 0.465 MHz; curve 2 - 1 MHz; curve 3 - 3 MHz; curve 4 - 5 MHz; curve 5 - 7 MHz, curve 6 - 10 MHz, (b) ON state (curve 1 -0.465 MHz, curve 2 - 5 MHz, curve 3 - 10 MHz)

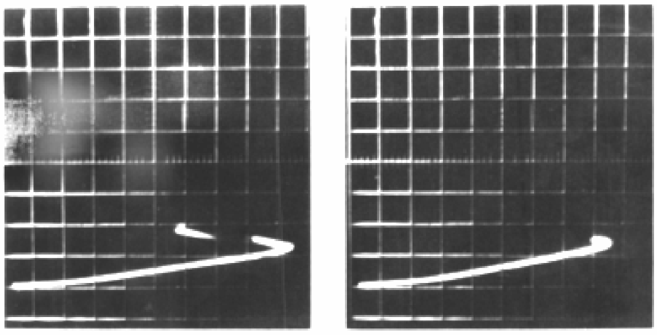

Fig.3. I-V-characteristics of a poly-Si film under reverse bias (a) without illumination and (b) under illumination (horizontal axis - 1V/division; vertical axis - 5 mA/division)

3. Discussion and conclusions

The capacitance transition observed in the OFF state could be explained in terms of carrier trapping by deep levels at the grain boundaries. In fact in the OFF state the capacitance of a poly-Si film is determined by depletion layers at the grain boundaries and must decrease with increasing reverse bias because of the widening of these layers (fig. 2,a, left side).With a further increase in bias a sequential breakdown of potential barriers takes place resulting in an of capacitance due to the contribution of free carriers injected into the depletion region.

Then, as seen from fig. 2,a, an abrupt decrease in the capacitance and its transition to negative values take place. The asymmetry of the C-V characteristics relative to the bias polarity is explained by the fact that, according to [6], in switching poly-Si films the potential barriers exist only on one side of the grain. Thus under forward bias the capacitance instantly increases the carrier injection (fig. 2,a, right side).

As has been shown [7] for the breakdown region of p-n junctions containing deep levels, the capacitive behavior of the reactive conductance changes into an inductive behavior as a result of carrier generation and capture. The presence of deep levels and barrier layers suggests that the observed transition of the capacitance to negative values in poly-Si films is also due to processes of recharging of their deep levels.

As the result of the breakdown, free carriers are injected into depletion layers where they are captured by deep traps at the grain boundaries. At a low injection level the relaxation time of deep levels is sufficiently long and satisfies the condition $1/\tau<\omega$ where ω is the cyclic frequency of the ac signal. Therefore the traps cannot follow the changes in the ac signal and do not participate in reactive conductance. The capacitance is positive. With increasing bias the injection level also increases. This is followed by an increase in the probability of free-carrier capture by deep traps, which results in a decrease in their relaxation time. At a definite injection level the condition $1/\tau=\omega$ is satisfied and the reactive conductance becomes zero. With a further increase in the bias voltage the ac signal frequency becomes lower than the frequency $1/\tau$ of free-carrier capture. Thus, while the ac signal is changing, the deep traps manage to capture and generate carriers. This results in a lagging phase shift between the current and the voltage, i.e. the films exhibit inductive behavior. The decrease in current due to illumination, which is shown by the disappearance of the S-shaped region, indicates that the poly-Si films exhibit negative photoconductivity. Similar phenomena are also connected with deep traps.

As known from [8], the deep level centers in semiconductors can have several charge states with corresponding different degrees of localization of the wave-function. The center charge states with $n>1$ may be shown on an electron band structure by the insertion of the correlated electron level which can exist in a conduction band. In this case it is possible for a conduction electron which traps a photon to jump from a zone into a local state, thus creating a negative photoconductivity.

In the ON state there are no potential barriers, the film resistance is low and the injection level is high. In this case the limiting factor of the capture and generation of free carriers is the intrinsic relaxation time of deep traps. This time corresponds to the intrinsic transition time from the OFF to the ON state, which according to [6] is of the order of 10 ns. Consequently, in poly-Si films in the ON state the transition of the capacitance to positive values, according to the condition ω>1/τ, can take place at ac signal frequencies higher than 15 MHz.

Thus, from the investigations carried out we concluded that a locally grown poly-Si film is a functional element with non-linear C-V-characteristics, having two stable conduction states with voltage-and light-controlled parameters, therefore it is possible to use them as the optonegatron elements.

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POLİKRİSTALLİK SİLİSİUMUN LOKAL PLYONKALARI ƏSASINDA OPTONEQATRON ELEMENTLƏRİN REAKTİV XASSƏLƏRİ

0,465÷10MHs diapazonunda monokristallik plyonkaların epitaksial yetişdirmə prosesində becərdilmiş polikristallik silisium lokal plyonkasının volt-tutum xarakteristikaları tədqiq edilmişdir. Reaktiv keçiriciliyin xarakterinin tutumdan induktivliyə inversiya effekti aşkar edilmişdir. İşıqlanmanın təsiri ilə induktiv xarakter əksinə tutuma keçir, VAX-dakı mənfi müqavimət hissəsi yox olur, deməli, polikristallik silisium lokal plyonkaları optoneqatron elementləridir. Göstərilmişdir ki, polikristallik silisium plyonkalarındakı induktiv hadisələri, dərin səviyyələrin yenidən yüklənməsi ilə əlaqədardır.

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РЕАКТИВНЫЕ СВОЙСТВА ОПТОНЕГАТРОННЫХ ЭЛЕМЕНТОВ НА ОСНОВЕ ЛОКАЛЬНЫХ ПЛЕНОК ПОЛИКРИСТАЛЛИЧЕСКОГО КРЕМНИЯ

В диапазоне 0,465÷10 МГц исследованы вольт-емкостные характеристики локальных пленок поликристаллического кремния, выращенных в процессе эпитаксиального наращивания монокристаллических пленок. Был обнаружен эффект инверсии характера реактивной проводимости из емкостного в индуктивный. Под влиянием освещения индуктивный характер переходил обратно в емкостный, а участок отрицательного сопротивления на ВАХ исчезал. Следовательно, локальные пленки поликремния являются оптонегатронными элементами.

Показано, что индуктивные явления в поликремниевых пленках обусловлены процессами перезарядки глубоких уровней.

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