

High-Photosensitive Avalanche-Mode Imaging Materials

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Abstract

For thin films of polymer amorphous analog of trigonal selenium, the analysis of the opportunity of the application of the discovered early avalanche phenomenon in strong-electric field in order to increase the photosensitivity of imaging materials is carried out. A theory of this phenomenon is developed and the regularities of avalanche effects are investigated. For thin (5 µm) polymer films, it is shown the possibility of achievement of an avalanche amplification coefficient of 1000 and a corresponding increase of photosensitivity. The avalanche phenomenon is perspective for high-sensitive avalanche-mode imaging materials, such as photothermoplastic materials, photo-conducting targets, LC-photoconductor modulators. It is problematically for xerographical photoreceptors.

Introduction

The creation of the imaging materials having a high recording density accompanied with a high photosensitivity is an actual problem. One of the ways of achieving the high recording density is to use for such materials, working in strong electric fields, high-resistance films of high-photosensitive semiconductors. For semiconductors mentioned above, as a result of high resistance, strong electric fields and low mobilities of charge carriers the diameter of scattering carrier taper through the thickness is less than film's thickness and a resolved element is a small. So, for film's thickness of 2-5 µm the resolving power is from 250 to 100 line pairs per mm, correspondingly. For amorphous semiconductor, a quantum gain of free charge carrier photogeneration is 1. Consequently, an average quantity of photogenerated charge carriers created by one absorbed photon is the maximal possible value for moderately high electrical fields and photon energies. It can be increasing under the action of a avalanche phenonenon. As it is known, such phenomenon is observed for crystal semiconductors having a high mobilities if charge carriers. For these conditions, a photogenerated charge carriers create new carriers and as a result of this avalanche phenomenon the photosensitivity of imaging materials increases. Among amorphous semiconductors the avalanche phenomenon takes place only for amorphous silicon and seleniun having a special structure. Early we discovered the avalanche phenomenon in polymer amorphous selenium films in strong electric field.[1] The increasing quantum gain in such electric fields as the result of impact ionization of selenium atoms. Discovered phenomenon is very perspective for the increase the photosensitivity of imaging materials. The aim of this work is to study of the dependencies of the avalanche phenomenon in polymer amorphous analog of trigonal selenium and the opportunity for the creation of the high-photosensitive avalanche-mode imaging materials.

Principles of Avalanche Phenomena

What is a principle of the avalanche phenomena? An appearance of avalanche phenomena is possible in strong electric fields. For an amorphous selenium photoconductor, in the cases of electric fields $F < 80$ V/µm one of the photons absorbed causes one of electron-hole connected pair. Its electron is moved to conducting layer and its hole is drifted to electrostatic contact without recombination (in the case of enough strong field). Quantum gain of charge free carrier photogeneration is equal to 1. For the same photoconductors, in the case of stronger electric fields $F > 80$ V/µm an absorbed photon causes one electron-hole pair too. But its hole is accelerated under the action of electric field. If its kinetic energy is high, the hole creates a new electron-hole pair as a result of impact ionization of seleniums atoms. Then, the holes have enough energy for the creation of a new pairs too. Described phenomenon is characterized by quantum gain of photocharging $q = k\, g$, where k—avalanche amplification coefficient. The value of q is significantly more than 1. So, as the result of the effect of strong electric fields there are a 100% assembling of photogenerated carriers and high values of the photosensitivity.

History of a Problem

During the last 20 years, for amorphous semiconductors, a opportunity of the increase of the photosensitivity based on the rising of charge carrier mobilities in strong electric fields to the level, which due to avalanche phenomena for charge carriers, is studied.[1-3] These phenomena were predicted by Mott[4] for amorphous semiconductors, if they have low carrier mobilities and, consequently, a smaller probability of carrier mobilities rising compared with crystal semi-conductor, but a zone model takes place as true. We proved a existence of zone model for amorphous selenium.[5] Therefore, for this material we began to look for an avalanche phenomena in strong electric fields. In addition, for n-p heterotransition of amorphous seleniums we achieved a amplification coefficient of 40.[1] Also, in the case of high photon energies, which are in 2.5 times or more then energy gap of semiconductor, we discovered a charge carrier multiplication in 3 times at photon energy of 11 eV.[1] The impact ionization in selenium films in strong electric field having a avalanche coefficient of 100 are described in work,[2] and avalanche-mode amorphous layers having a coefficient of 1000 are studied.[3]

Avalanche-Type Structure of Imaging Material

What are the requirements for the achievement of avalanche phenomenon for charge carriers? There are four requirements. One of them is the fulfillment of a zone model. A second is an exceeded drift mobility, for example the hole mobility over electron mobility. A third is a presence of the barrier layers in order to eliminate the injection of charge carriers from a contacts. A fourth is an optical signal recorded to diminish of electric field needed for avalanche phenomenon. First and second requirements are fulfilled for polymer amorphous analog of trigonal selenium. For it a charge carrier mobility is a zone character.[1] In distinction from hopping carrier transport, the charge carrier are able to acquire an energy, which is need for the impact ionization of selenium atoms. Also, the hole mobility is more than electron mobility. So, a condition of high-speed kinetic of avalanche amplification takes place. In the opposite case, the avalanche amplification is realized simultaneously for electron and for holes and resulted effect of contrary streams is relaxated. Others two requirements denote a special structure and its working regime. Let's consider a structures of the imaging material, for which four requirements mentioned above are fulfilled. There are two types of the structures: the structure having a free charged surface and the sandwich-structure. A first of them is as a xerographic photoreceptor, photothermoplastic material and a photoconducting target, a second—for a light modulator LC-photoconductor. A polymer amorphous selenium layers are coated using vacuum thermal stable evaporating having ruled temperatures of melting and vapour, of coating rate and conditions of molecular structure's stabilization.[6] The structure is based on a glass substrate having transmitting conductive coating of 100 nm, first barrier layer of 20 nm, amorphous Se layer of 1.9 - 4.0 µm, second barrier layer and electrostatic contact. If to the first structure, a voltage of any hundreds volts is impressed, into seleniums layer a strong electric field is applied. This electric field is able to implificate the photogenerated charge carriers. So, the conditions for avalanche phenomenon are achieved. On the surface of imaging material, as a result of action of light a potential (charge) relief is created. This relief is reading by means of electrostatic or optical detector. The quantum gain is measured according the method described.[1,6] In the case of red-sensitive, the layers of Se-Te doped As are added: the Se-As-layer of 10 nm, the SeTe (17%) As layer of 50-120 nm and SeAs + 5%As layer. For the photothermoplastic imaging material, a organic deformed layer based on styrene—polyvinylcarbazole (PVC) is added.

Experimental Results

As shown in our last investigations, the properties of amorphous selenium, which are due to the appearance of the avalanche effects, are depended on the selenium structure.

They are most likely for amorphous form of trigonal selenium, which is consists of a spiral molecules, and they are not realized for amorphous form of monoclinic selenium, which is as an 8-atomic ring molecules. Let's consider the experimental results concerned with the realization of the avalanche phenomenon. For structure having a free charge surface, the dependencies of quantum gain of photocharging q from the electric field E and from the selenium layer's thickness d are studied. The q vs d for E = const is characterized by logarithmic relationship. So, in the case of electric field of 120 V/µm for d = 2 µm q = 8, for d = 4 q = 30, in the case of the electric field of 140 V/µm for d = 2 µm q = 40. The dependence mentioned above takes the form of q is equal to d in degree of a(E), where a(E) is a slope of function q(d). From given dependence it is seen, that for E = 140 V/µm the value of q = 1000 can be achieved for d = 5 µm, i.e. for smaller thickness than in work.[3] The dependencies of light and dark current vs voltage are studied too. The light current vs voltage (for film's thickness of 2 µm) is described a curve characterized by three sections. At the first section (from 0 to 60 V) light current is increasing with the increase of voltage and then it is saturated. At the second section (from 60 to 180 V) it is voltage-independent. At the third section (from 180 to 260 V) the light current is exponentially increasing (in 100 times) as a voltage linear increasing. A dark current is also exponentially increasing (in 1000 times) with voltage rising over third section. Over third section the avalanche phenomenon is observed. In order to establish the nature of phenomenon under investigation nature is studied the dependencies of induced surface charge vs voltage using a flight-time method[6] for electron and hole drifting. In the case of electron drifting the saturation is absent, for hole drifting the saturation is present and it is followed by exponential increasing of q. From the dependence of quantum gain of photocharging q vs film's thickness d can be defined a hole and electron ionization rates. They are exponential dependent from electric field. For polymer amorphous analog of trigonal selenium, the hole ionization rate is equal to 6300 cm^{-1}, and the electron ionization rate is 130 cm^{-1}, i.e. the hole ionization rate is more than electron rate. Let's estimate the electric field value, for which the avalanche phenomenon is observed. For the impact ionization it is necessary that the energy, acquired between the ionization acts, can be exceeded the dispersed energy. For zone mobility of 1 V/cm^2s the electric field value, for which the avalanche amplification takes place, is nearly 100 V/µm and this magnitude is corresponded good to experimental data. Let’s consider the signal noise ratio in the case of avalanche amplification. The level of own noise of system for amorphous semiconductor is less than for the crystal semiconductor. There two reasons of this observed phenomenon. First of them is a value of coefficient characterised the dependence q vs electric field. As this coefficient is small, the noise is higher. For crystal selenium it is 2.1, for amorphous it is 2.8. The second reason of phenomenon is a strong (exponential) dependence of mobility from electric field. As a result of this reason a signal is rising is more high than noise is increasing. So, the signal noise ratio is increasing.

Perspectives of Imaging Material's Development

Field modulation depth is achieved under the action of the light signal are investigated for different imaging materials. For photoconducting targets the modulation depth is equal to 5-7% (value is corresponded to changing of q in more than 3 times), for photothermoplastics material, it is equal to 30% for created materials, and 3-5%—for perspective thermoplastic media, which is now under the investigations in the laboratory, for modulator LC-photoconductor it is 5-7%, for xerographic photoreceptors—nearly 90% for classic xerography and 5-7 for photoreceptors with fluid development (data are absent). From results mentioned above, it is seen, that the avalanche phenomenon are perspective for the creation of the photoconducting targets, photothermoplastic materials, modulator LC-photoconductor. The classic xerographic photoreceptors based on avalanche phenomena can be not created. A preliminary study of the photoconducting targets in avalanche regime for q = 40 is shown, that a image has high quality, which is not achieved for others high-photosensitive devices. A resolution is more than 100 line pairs per mm, accompanied by low-noise.

Conclusion

Comparing our achieved results with other avalanche-mode materials,[2,3] it is seen that the realization of high quantum gain of photocharging (to 1000) in our avalanche-structures is possible for smaller thicknesses of polymer amorphous analog of trigonal selenium layers than for other selenium’s structures. It is interest for the creation of high-photosensitive imaging materials[7,8] because of it is need a creation of smaller electric fields in order to achieve equal effect.

References

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