Study of a Fabrication Process and Characterization of One Dimensional Array of Un-cooled Micro-bolometers...

Conference Paper · January 2007

4 authors:


Mario Moreno
Instituto Nacional de Astrofísica, Óptica y Elect...
95 PUBLICATIONS **410** CITATIONS
SEE PROFILE


A. Kosarev
Instituto Nacional de Astrofísica, Óptica y Elect...
123 PUBLICATIONS **571** CITATIONS
SEE PROFILE

Alfonso Torres Jacome
Instituto Nacional de Astrofísica, Óptica y Elect...
177 PUBLICATIONS **655** CITATIONS
SEE PROFILE


ROBERTO C. Ambrosio
Benemérita Universidad Autónoma de Puebla
98 PUBLICATIONS **372** CITATIONS
SEE PROFILE

Mater. Res. Soc. Symp. Proc. Vol. 989 © 2007 Materials Research Society 0989-A19-01

Study of a Fabrication Process and Characterization of One Dimensional Array of Un-cooled Micro-bolometers Based on Germanium Films Deposited by Plasma

Mario Moreno, Andrey Kosarev, Alfonso Torres, and Roberto Ambrosio
Electronics, Institute National of Astrophysics, Optics and Electronics, L.E. No. 1 Tonanzintla., Puebla, 72840, Mexico

ABSTRACT

In our previous works, we have studied the fabrication process and characterization of single cell micro-bolometers based on germanium thin films deposited by low frequency (LF) PECVD technique at low temperature and fully compatible with the IC fabrication technology. We have demonstrated promising properties of those devices for further development of IR imaging systems [1-2].

In this work, we report the study and characterization of the fabrication process of a lineal array of 32 un-cooled micro-bolometers. We have used surface micro-machining techniques for the array fabrication onto a silicon wafer. The micro-bolometers in the array have a "bridge type" configuration. In this case, a SiN_x supporting film is suspended 2.5 µm from the substrate by two legs, which form the bridge and provide sufficient thermo-isolation to the thermo-sensing layer. The thermo-sensing layer was deposited on the bridge by using LF PECVD. The a-Ge_xSi_y:H film used in this devices showed high activation energy E_a= 0.34 eV, providing high thermal coefficient of resistance, TCR=α=0.043 $K^{-1}$and improved but still high resistance. We studied the effect of the addition of boron to the a-Ge_xSi_y:H film deposition process, for reducing its undesirable high resistance and, the resulting layer (a-$Ge_xB_ySi_z$:H) is used as thermo-sensing film in the micro-bolometers arrays. The active area of the cell in the array is A_b=70x66 µm^2 and the area of the array including interconnection lines and pads is A_A=1600x3120 µm^2. The temperature dependence of conductivity σ(T), current-voltage characteristics I(U), and spectral noise density have been measured in the array and the main figures of merit such as, responsivity and detectivity have been obtained.

INTRODUCTION

The maturity of the MEMS structures fabrication process through the surface micro-machining techniques, has allowed the development of low cost and reliable night vision systems based on thermal detectors [3-4]. Among the thermal detectors used for IR arrays, the micro-bolometer is one of them. The main requirements for the thermo-sensing materials used in micro-bolometers are: high value of the temperature coefficient of resistance, TCR (α(T)), defined as $\alpha\ (T) = (1/R)|dR/dT| = E_a/kT^2$, where E_a is the activation energy, moderated resistivity, low noise and compatibility with standard IC fabrication processes. Currently, it have been developed large arrays of un-cooled micro-bolometers that use different thermo-sensing materials. But none of them can be consider as the optimum one. Among the materials preferably used as thermo-sensing films are vanadium oxide, amorphous and polycrystalline semiconductors, and some metals [5-6]. Those materials have shown advantages and disadvantages. Vanadium oxide has a high value of TCR but it is not a standard material in IC technology, resulting in a more complex fabrication process with special installations.

Metals are compatible with the standard IC fabrication technology, have low resistance but low values of TCR, which is transformed in a low responsivity.

Amorphous silicon (a-Si:H) has showed high values of TCR and is fully compatible with the silicon technology. However, intrinsic amorphous semiconductors have very high resistance, which often cause a mismatch with the read out circuits. In order to reduce the high resistance of amorphous materials, boron doping has been employed.

In our previous work intrinsic a-Ge_xSi_y:H films obtained by PE CVD were used as thermo-sensing layers in micro-bolometers, providing high activation energy and improved, but still high resistance. We demonstrated promising properties of those devices for further development of IR imaging systems [1-2]. In this work we have added boron during the deposition process of the a-Ge_xSi_y:H thermo-sensing film for reducing its high resistance. The resulting film (a-$Ge_xB_ySi_z$:H) was also used as thermo-sensing film in micro-bolometers. With these films, we have fabricated one dimensional arrays (1-D) of 32 elements with the both types of thermo-sensing films: a-Ge_xSi_y:H and a-$Ge_xB_ySi_z$:H. We selected one cell of each array and such characteristics as responsivity, spectral density of noise, and detectivity were compared.

EXPERIMENT

The micro-bolometer arrays fabrication process is as follows. A 200 nm-thick SiO_2 layer was thermally grown on a c-Si wafer and a 2.5 μm-thick aluminum layer was deposited by e-beam evaporation over it, the aluminum layer is used as sacrificial film. A lithographic step and wet etching is carried out in order to pattern the aluminum layer. A 0.8 μm-thick SiN film was deposited at low temperature (350^{o}C) by low frequency PE CVD over the aluminum pattern. The SiN film is patterned by reactive ion etching (RIE) in order to form a SiN bridge over the aluminum pattern. A 200 nm-thick titanium layer was deposited by e-beam evaporation over the SiN bridge, and it was patterned in order to form the contacts. A 0.5 μm-thick thermo-sensing a-Ge_xSi_y:H film was deposited over the Ti contacts by low frequency LF PECVD technique at a rf frequency f=110 kHz, temperature T=300 ^{o}C, power W=350 W and pressure P=0.6 Torr. The a-Ge_xSi_y:H film was obtained from a SiH_4 (100%)+ GeF_4 (100%) + H_2 (100%) mixture with gas, at the following gas flows: Q_{SiH4}=25sccm, Q_{GeF4} =25 sccm, Q_{H2}=1000 sccm, resulting in a Ge content in solid phase Y=0.88 and a Si content in solid phase Y=0.11, SIMS was used for the content determination. The thermo-sensing film was covered with a 0.2 μm-thick SiN film deposited by PE CVD. The active area was patterned by RIE and finally, the aluminum sacrificial layer was removed by wet etching.

The boron alloy thermo-sensing film (a-$Ge_xB_ySi_z$:H), was deposited with the same conditions as those for of the a-Ge_xSi_y:H film, but with different gas mixture. The film was deposited from a SiH_4 (100%) + GeF_4 (100%) + B_2H_6 (1%) mixture with the following gas flows: Q_{SiH4}=50sccm, Q_{GeF4} =50 sccm, Q_{B2H6}=5 sccm. This results in a Ge content in solid phase Y=0.675, B content in solid phase Y=0.262 and Si content in solid phase Y=0.055.

The active area of the thermo-sensing layer is A_b=70x66μm^2 and the area of the array including interconnection lines and pads is A_A=1600x3120 μm^2. A SEM picture of a top view of one micro-bolometer in the array is shown in Figure 1 a) and a SEM picture of a fragment of the 1-D array is shown in Figure 1b). The performance of the micro-bolometers in the arrays was studied through the measurement of I(U) characteristics in dark and under IR illumination conditions. The source of IR light is a “Globar”, which provides an intensity I_0=5.3x10^{-2} W/cm^2 on the surface of the sample. The samples were placed in a vacuum thermostat and illuminated through a zinc selenide window (ZnSe). The window has a 70% of transmission in the range of λ=0.6 – 20 μm. The I(U) measurements were performed at pressure $P \approx 10$ mTorr, at room temperature, current was measured with an electrometer (“Keithley”- 6517-A) and the applied voltage was varied from U = 0 to 7 V. The responsivity was calculated from the I(U) measurements. Noise measurements in the micro-bolometers were performed with a lock-in amplifier (“Stanford Research Systems” - SR530). The noise of the system and the total noise (system + cell noise) were measured separately, and a subtraction of the system noise allowed us to obtain the noise of the device. The detectivity was calculated from the I(U) characteristics and noise measurements.

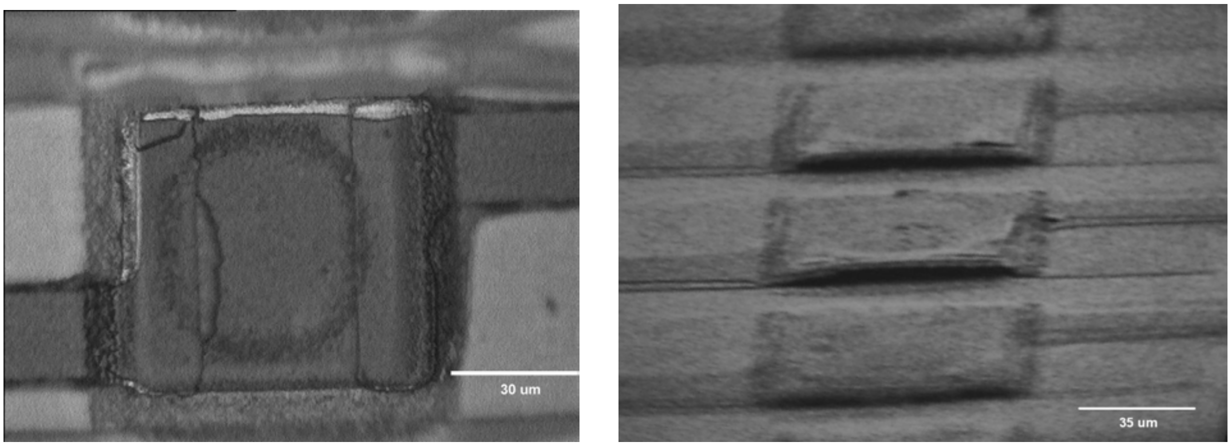

Figure 1. a) Top optical view of one micro-bolometer in the array, b) SEM picture of a fragment of 1-D 32 elements array.

DISCUSSION

We have measured the temperature dependence of conductivity with increasing and decreasing temperature, in the range of 300K to 400K on both the a-Ge_xSi_y:H, and the a-$Ge_xB_ySi_z$:H thermo-sensing films. The activation energy for the a-Ge_xSi_y:H thermo-sensing film measured in a test structure is E_a=0.34 eV, which provides a TCR α=0.043 K^{-1} and a measured conductivity at room temperature σ_{RT}=6x10^{-5} $Ohm^{-1}cm^{-1}$. The activation energy of the a-$Ge_xB_ySi_z$:H film measured in a test structure is E_a=0.21 eV, which results in a TCR α=0.027 K^{-1} and the conductivity at room temperature σ_{RT}=1.3x10^{-2} $Ohm^{-1}cm^{-1}$.

For a complete characterization and comparison of the devices with the different thermo-sensing films, a device from the array with a-Ge_xSi_y:H film, and other from the array with the a-$Ge_xB_ySi_z$:H film were selected. The current-voltage I(U) characteristics in dark and under IR illumination are shown in Figure 2 for both type of micro-bolometers in the arrays. Linear I(U) characteristics are observed for both type of devices, as it is demonstrated in the inserts in Figures 2 a) and 2 b).

Figure 3 shows the responsivity for the micro-bolometers with the a-Ge_xSi_y:H (3a) and a-$Ge_xB_ySi_z$:H thermo-sensing films (3b). The responsivity R_I, is defined as $R_I=(I_{IR}-I_d)/I_0$, where, I_{IR} is the current under IR illumination, I_d is the dark current, and I_0 is the incident IR intensity. From Figure 3 it can be seen that R_I for the a-Ge_xSi_y:H thermo-sensing film micro-bolometer, is one order of magnitude smaller than that of the a-$Ge_xB_ySi_z$:H thermo-sensing film micro-bolometer for the same bias voltage and IR illumination conditions. However, the relative responsivity (I_{IR}/I_d) is larger for the a-Ge_xSi_y:H film micro-bolometer.

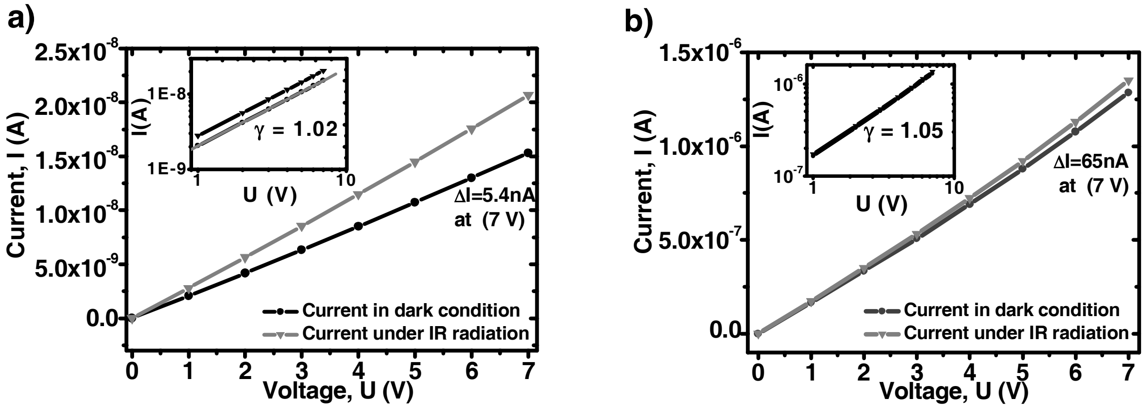

Figure 2. I(U) characteristics of micro-bolometers for: a) a-Ge_xSi_y:H and b) a-$Ge_xB_ySi_z$:H thermo-sensing films. In the inserts the I(U) curves are shown in double log scales.

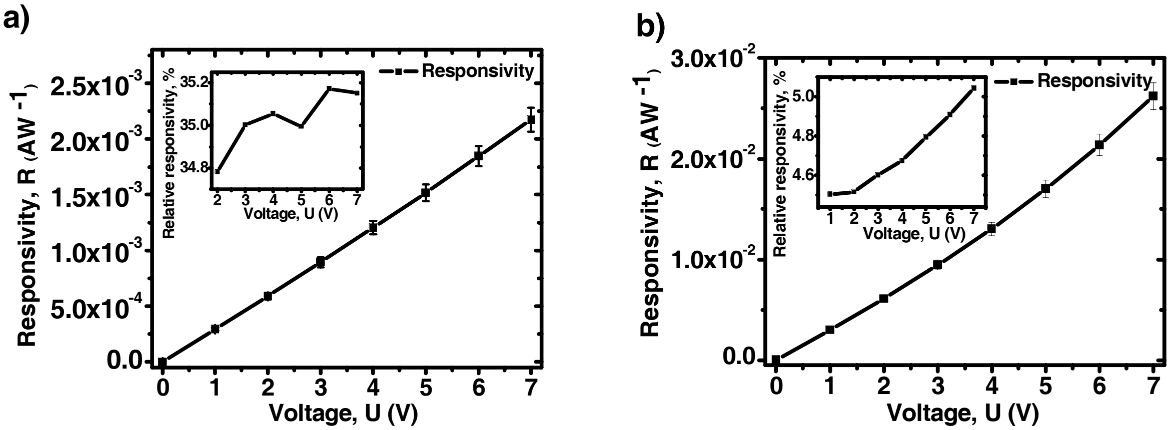

Figure 3. Responsivity of micro-bolometers for: a) a-Ge_xSi_y:H thermo-sensing film and b) a-$Ge_xB_ySi_z$:H thermo-sensing film. The inserts show relative responsivity versus bias voltage.

The current noise spectral density (NSD) $I_{cell\ noise}$ (f) for both micro-bolometers is shown in Figure 4. Where $I_{cell\ noise}(f) = I_{cell\ +\ system\ noise}(f) - I_{system\ noise}(f)$, $I_{cell\ +\ system\ noise}(f)$ is the NSD measured at the micro-bolometer cell in with the measuring system. The $I_{system\ noise}(f)$ is the NSD measured in the system without the micro-bolometer cell. The $I_{cell\ noise}$ (f) values observed for a-Ge_xSi_y:H thermo-sensing film micro-bolometer are around one order of magnitude smaller than that of the a-$Ge_xB_ySi_z$:H film micro-bolometer as it is presented in Figure 4.

From the measured responsivity and noise we have calculated detectivity D^* for both devices. For The a-Ge_xSi_y:H thermo-sensing film device we obtained $D^*= 7x10^9$ $cmHz^{1/2}W^{-1}$ while for the a-$Ge_xB_ySi_z$:H micro-bolometer $D^*= 5.9x10^9$ $cmHz^{1/2}W^{-1}$. It is important to note that both values of detectivity are very similar. This is because the a-$Ge_xB_ySi_z$:H micro-bolometer show both higher responsivity and higher noise with respect to those in a-Ge_xSi_y:H film device. The measured performance characteristics of the devices here studied are listed in Table 1, and are compared with data recently reported in literature.

Additionally, we have studied the yield of the fabrication process here presented. It is found that the 1-D arrays with a-Ge_xSi_y:H film resulted in an average yield of 50% (on 15 measured arrays containing 476 cells), while the 1-D arrays using a-$Ge_xB_ySi_z$:H film had an average yield of 60% (19 measured arrays containing 608 cells). In order to compare the average responsivity of the fabricated arrays with the films studied, we have selected one array of each type. After measurements of each one of the cells conforming the array it was found the following: The 1-D array with the a-Ge_xSi_y:H micro-bolometers resulted in a yield of 60%, with an average responsivity of 1.2 $x10^{-3}$ AW^{-1}. While the 1-D array with the a-$Ge_xB_ySi_z$:H micro-bolometers showed a yield of 85% with an average responsivity of 1.5 $x10^{-2}$ AW^{-1}. Figure 5 shows the normalized responsivity (R / R_{max}) for both micro-bolometers arrays.

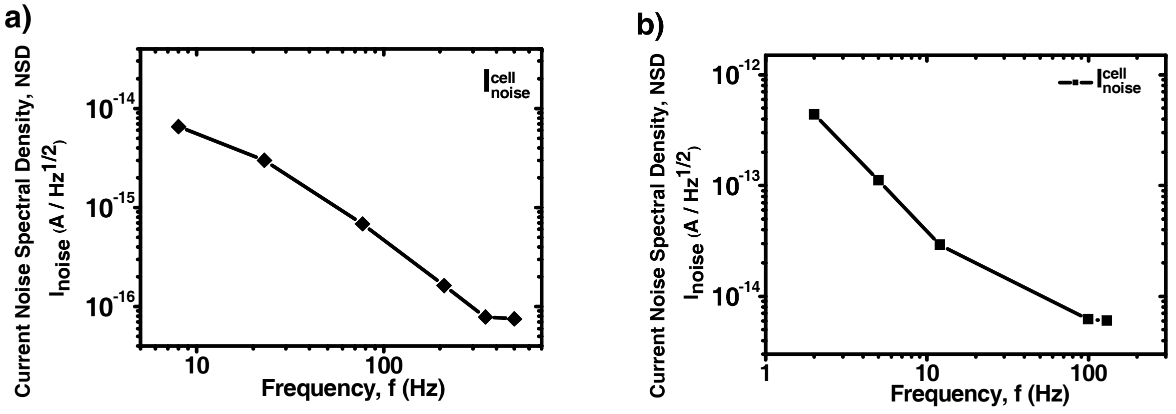

Figure 4. Current noise spectral density I_{noise}, as a function of frequency for the micro-bolometers with a) a-Ge_xSi_y:H thermo-sensing film and b) a-$Ge_xB_ySi_z$:H thermo-sensing film.

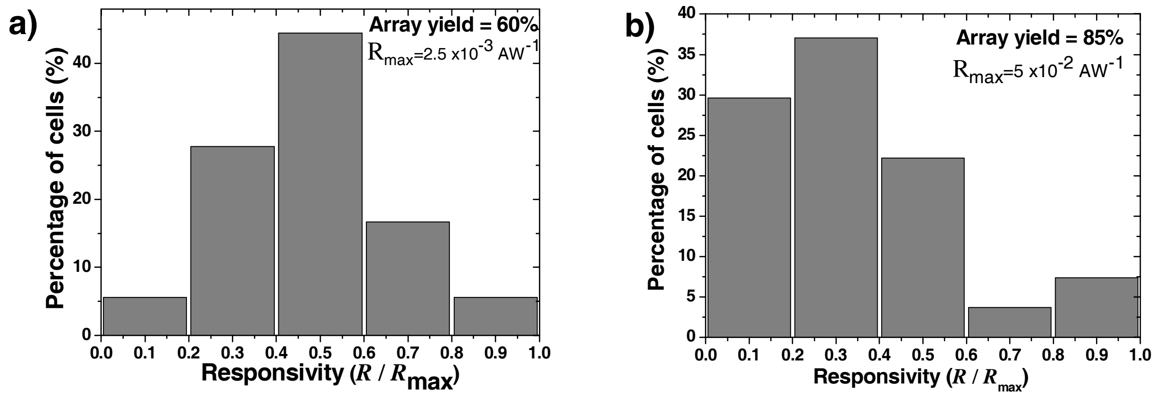

Figure 5. Yield of the cells as a function of normalized responsivity of two 1-D arrays: a) a-Ge_xSi_y:H thermo-sensing film micro-bolometers and b) a-$Ge_xB_ySi_z$:H thermo-sensing film micro-bolometers.

CONCLUSIONS

1-D arrays of 32 elements with two different thermo-sensing films: intrinsic thermo-sensing film (a-Ge_xSi_y:H) and boron alloy thermo-sensing film (a-$Ge_xB_ySi_z$:H) have been fabricated and characterized. From the characterization we can conclude: The intrinsic thermo-sensing film has larger activation energy, E_a = 0.34 eV and consequently higher TCR than the boron alloy thermo-sensing film, E_a = 0.21 eV. However, the intrinsic film resistivity is 3 orders of magnitude larger than the boron alloy film resistivity. The responsivity of the boron alloy film micro-bolometer is one order of magnitude larger than that of the intrinsic film micro-bolometer. The boron alloy film micro-bolometer resulted in a noise density of 1 order of magnitude larger than that of the intrinsic film micro-bolometer. As a consequence, the detectivity of both devices is very similar, ($D^*= 7x10^9$ $cmHz^{1/2}W^{-1}$ for the intrinsic film micro-bolometer and $D^*= 5.9x10^9$ $cmHz^{1/2}W^{-1}$ for the boron alloy film device). In spite of that, both devices showed similar detectivity and the boron alloy film micro-bolometer showed 2 orders of magnitude less resistance than that of the intrinsic material. The comparison in the average responsivity of both type of arrays resulted in the following: The 1-D array with the intrinsic film micro-bolometers had an average responsivity of 1.2 $x10^{-3}$ AW^{-1} while the 1-D array with the boron alloy film micro-bolometers had an average responsivity of 1.5 $x10^{-2}$ AW^{-1}.

Table 1. Comparison of the two types of micro-bolometers with literature.

Thermo sensing layer	$E_{a,}$ eV	TCR,α K^{-1}	Pixel area, A_b, μm^2	Pixel resistance, R_b, Ohm	Voltage responsivity $\Re_{U,}$ VW^{-1}	Current responsivity $\Re_{I,}$ AW^{-1}	Spectral Response,μm	Detecti vity, D^* $cmHz^{1/2}W^{-1}$	References
$Ge_xSi_{1-x}O_y$	-	0.048	50 x 50	-	$1x10^5$	-	10	$6.7x10^8$	[5]
a-Si:H,B	-	0.028-0.039	48 x 48	3 $x10^7$	10^6	-	5 - 14	-	[6]
a-Ge_xSi_y:H	0.34^*	0.043	70 x 66	$5x10^8$	$7.2x10^5$	$2x10^{-3}$	2 - 14	$7x10^9$	a-Ge_xSi_y:H micro-bolometer
a-$Ge_xB_ySi_z$:H	0.21^*	0.027	70 x 66	$6x10^6$	$2.8x10^5$	$2.6x10^{-2}$	2 - 14	$5.9x10^9$	a-$Ge_xB_ySi_z$:H micro-bolometer

* Measured in a test structure.

ACKNOWLEDGMENTS

The authors acknowledge the support of this research by CONACyT project No. 48454 and greatly appreciate Dr. Yu. Kudriavtsev, CINVESTAV, Mexico, for SIMS measurements and analysis. M. Moreno acknowledges CONACyT for support granted through scholarship # 166011.

REFERENCES

1. R. Ambrosio, A. Torres, A. Kosarev, A. Illinski, C. Zúñiga, A. S. Abramov, *J. Non-cryst. Solids*, 338-340, 91-96 (2004).
2. A. Torres, A. Kosarev, M. L. García Cruz, R. Ambrosio, *J. Non-cryst. Solids*, 329, 179 - 183 (2003).
3. R. Ambrosio, A. Torres, A. Kosarev, M. Moreno, *Book of Abstracts ICANS 21 – Science and Technology,* WO4.4, 215 (2005).
4. T. Adrega, M. Almeida, D.M.F. Prazeres, V. Chu, J.P. Conde, *Journal of Non-Crystalline Solids,* Volume 352, Issues 9-20, Pages 1999-2003, June 2006.
5. A. H. Z. Ahmed, R. N. Tait, *IEEE Trans Electr.Dev.,* v52(8) 1900-1906 (2005).
6. A. J. Syllaios, T. R. Schimert, R. W. Gooch, W. L. Mc.Cardel, B. A. Ritchey, J. H. Tregilgas, *Mat. Res. Soc. Symp. Proc.* 609 A14.4.1 (2000).