Nanometer Thick Diffused Metal Oxide Light Sensing Film Structures

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Summary Material for Tampa, AVS abstract

A high degree of light sensitivity has been observed in metal-oxide diffused structures made by successively sputtering a metal in oxygen, then argon, and then oxygen. Some results for hafnium and titanium film structures have previously been reported. More recently light sensitive structures have been made using other metals, notably aluminum that show this methodology to be fairly general. An example of the type of light response observed is illustrated in Fig. 1. The geometry of the film layer structures are as illustrated in Fig. 2 so that contacts are deposited in a crossed railroad tie arrangement below and above a thin diffused metal oxide film structure. Samples have been made that exhibit more than a factor of 40 increase in junction current upon exposure to light at a +3 volt bias voltage; and very little response for a -3 volt bias as illustrated in Fig. 1. The film layering of these devices have been analyzed by X-ray reflectivity. In order to fit the reflectivity data it is necessary to account for a diffused oxygen depleted layer. The special feature of this film layer is that the through the film thickness electrical resistance can be changed by exposure to certain wavelengths of light and in the most general case for light across the entire visible and near infrared range of light wavelengths. The change in the electrical resistance also exhibits a diode type character in that the change in electrical resistance upon exposure to light only occurs when a bias voltage is applied in what is termed the negative direction. It should be noted that because the thin film structure exhibits a high lateral electrical resistance that it has not been necessary to pattern the thin film structure in any way to have each junction region act independent of any other junction region. The top and bottom conducting stripes can be metallic stripes of a metal such as aluminum or a transparent conducting material such as graphene. Graphene stripes have been successfully used as transparent conductors in order to avoid any shadowing by the conducting stripes.[1] In principle patterned conducting stripes can be deposited by a 3-d printing process although at the present time higher than desirable temperatures are required to deposit conducting stripes.

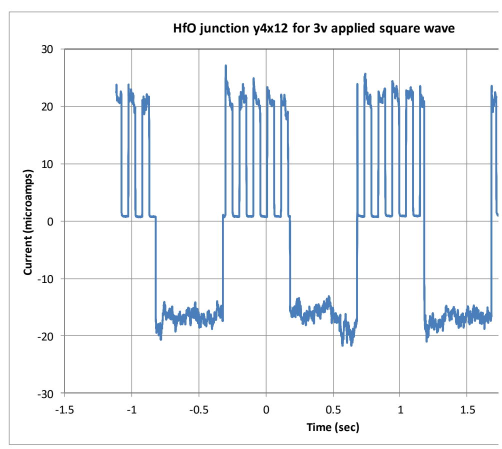


Fig. 1. The current passing through the thickness of a film layer structure is shownfor a 3 volt square wave bias in the prescence of a white LED strobe light operating continuously.

As illustrated in Fig. 2 samples with an array of 75 junctions have been deposited onto 26 mm x 60 mm silicon device substrates. The junctions have been labeled yj,xi where j can range from 1 to 5, and i from 1 to 15. A voltage of ≈3 V was applied across the junctions one at a time in series with a 5 to 50 kilo-ohm current sensing resistor.

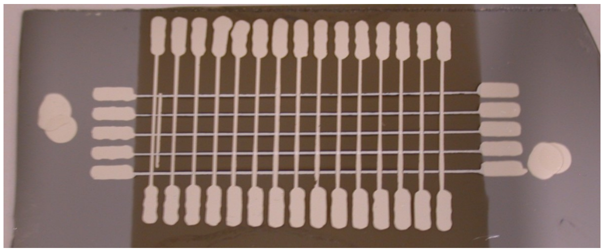
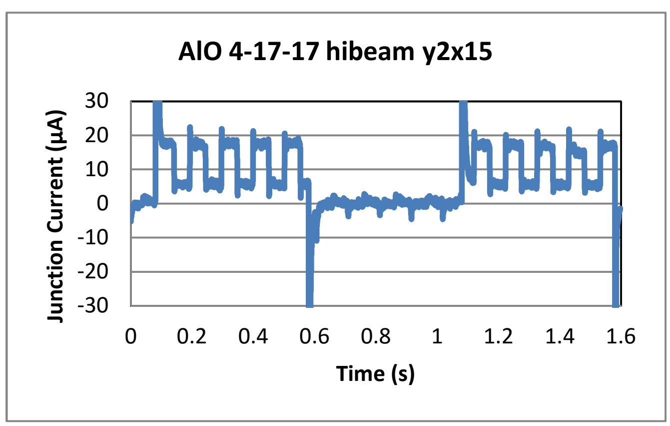


Fig. 2. This picture shows a Hf based sample made onto a silicon substrate. The silicon surface shows as grey in the picture. Next aluminum conducting stripes y1, y2, …., and y5 were evaporated onto the oxidized silicon surface. Next Hf was sputtered in oxygen, then in Ar, and then in oxygen again with the silicon surface heated to a temperature sufficiently high to cause diffusion to occur. The initial Hf in oxygen sputtering was for about 3 times as long as the final layer which acted to yield diode type current versus voltage behavior. The hafnium oxide diffused region shows as brown in the photograph and is mostly transparent since it has a total thickness of approximately 10 nm. Finally Al cross stripes x1, x2, x3,……x15 were evaporated.

The current-voltage behavior of the junctions has been modeled in terms of interface states to explain the light sensitivity only when biased in one voltage polarity, and insensitivity when reverse biased. This model can account for the observed unidirectional light sensitivity.

A new result that shows this method to be capable of making entirely new artificial materials is that we have made laminates by sputtering simply aluminum in sequentially oxygen, and then in argon, that exhibit high light sensitivity. The diagram below shows some results for a recent Al_2O_3-AlO structure made onto intrinsic silicon. The diagram shows the current passing up through the thickness of the film structure between a set of contacts below and above the film. The sample here is biased by a 1 Hz 2 volt amplitude square wave while the structure is exposed to a constantly blinking white LED strobe light. As shown here samples can be made which respond to the light only when biased in one direction and not in the other direction.

Fig. 3. This sample was made by sputtering Al in pure oxygen, then Al deposited in Ar, followed by a capping layer of Al deposited in oxygen. The substrate was intrinsic silicon. A junction was biased by a 2 V 1 Hz square wave while continuously illuminated by a white LED strobe light.



1. F.J. Cadieu, Device with Light-Responsive Layers. US Patent No. 9,040,982.
2. F.J. Cadieu and Lev Murokh, Nanometer Thick Diffused Hafnium and Titanium Oxide Light Sensing Film Structures, *World Journal of Condensed Matter Physics* **7**, 36-45 (2017).
3. F. J. Cadieu, I. Vander, Y. Rong, and R. W. Zuneska, X-ray measurements of nanometer-thick tantalum oxide and hafnium oxide films on silicon substrates for thickness and composition determination, Powder Diffraction **27**, 87-91 (2012).