Linear CCD-Imagers with a Polyimide Insulation for Double Level Metallization

A. J. P. THEUWISSEN, STUDENT MEMBER, IEEE, AND G. J. DECLERCK, MEMBER, IEEE

Abstract—**CCD-imagers have been fabricated with a double metallization and with polyimide (PI) as insulating layer between the two metals. The incorporation of PI reduces the complexity of the CCD-technology without changing the electrical and the optical properties of the imaging devices. In addition, the sensor uniformity is strongly improved due to the enhanced surface flatness.**

INTRODUCTION

EVERY semiconductor process which utilizes a double metallization requires a high quality insulating layer in terms of electrical, mechanical, and chemical characteristics. This work studies the use of polyimide as insulation between two aluminum layers in our standard double or triple poly CCD-process.

To fabricate linear CCD-imagers, a two level metallization was used. The first aluminum layer defines all the interconnection lines and the bonding pads, and the second metal film constitutes the light shield above the shift-registers and the field areas.

Until now, a thick (2.5 μm) P-doped CVD SiO_2 (PSG) film, deposited at low temperature, was used to isolate the two metal levels. The major disadvantages of this insulating film are:

- high defect density,
- moderate to bad step coverage, and
- it is difficult to etch with a uniform and limited degree of under-etching.

On the other hand, polyimide is a thin film with a low number of defects that covers the surface topography excellently and can be etched in a controlled way [1-4]. Thus, PI is an attractive alternative when compared with PSG.

PI-TECHNOLOGY

The polyimide PI-2555, manufactured by DuPont, was used as an insulator. It is deposited by a spin-on coating technique. Depending on the speed of the spinner and the viscosity of the polyimide, films between 1 and 2 μm can be applied in one step.

Curing of the films was done in a small furnace in a dry nitrogen atmosphere. Cure times and temperatures were given in the PI data sheets of the supplier.

Although the etching process is critical, wet etching of the PI-film can be done if the temperature during the cure cycles is exactly controlled. However, the most common way to generate patterns in the PI-film is to use plasma etching, preferably in an oxygen atmosphere [2]. With an optimized process, holes of 4 μm × 4 μm can be etched in the PI-film.

While the etching of the PSG-insulator required one photo-step, the definition of the vias in the PI-film was done by using the second metal layer (the light shield) as an etch-mask. This procedure implies that one photo-step and one mask can be omitted during the processing sequence.

RESULTS AND DISCUSSION

Two types of linear CCD-imagers have been fabricated with 512 photo-sensitive elements to evaluate the new material. The sensors have a pitch of 12 μm and are isolated from each other by a 5 μm-wide field region. In the perpendicular direction, the sensor width, as defined by the aluminum shield, is 12 μm. The first CCD had a PSG dielectric of 2.5 μm and the second one used PI, with a thickness of 2 μm, to isolate the two levels of metal. Both metallizations were dc-magnetron sputtered Al-Si (1%), with a thickness of 1 μm. All the other processing steps were common for the two types of devices.

Table I gives the different parameters measured during the process evaluation. The density of interface-states (D_{it}), the thermal relaxation time of a pulsed MOS-capacitor (t_s), the threshold voltage (V_T), the threshold voltage on the field (V_{TF}), and the breakdown voltage of the diodes (V_{BD}) are characterized. From these figures, the conclusion was made that the PI does not affect the process characteristics measured on test capacitors and MOS-transistors. The same statement can be made about the electrical and optical properties of the imagers. When PI is applied in the CCD-technology, the dark current, the dark current uniformity, the transfer efficiency, the spectral response, the quantum-efficiency, and the light sensitivity all remain unchanged. The only parameter which is affected is the sensor non-uniformity. This parameter is illustrated in Fig. 1 as a function of the wavelength of the incident light.

The resulting gain in sensor uniformity, especially for short wavelengths, by applying PI instead of PSG is significant. This effect should be regarded in connection with the etching of the aluminum light shield above the sensors. The gap in the

---

Manuscript received June 28, 1982.

The authors are with ESAT Laboratory, Catholic University Leuven, Kard. Mercierlaan, 94, B-3030 Heverlee, Belgium. G. J. Declerck is also a Senior Research Associate of the Belgian National Fund for Scientific Research.

0193-8576/82/1000-0308$00.75 © 1982 IEEE

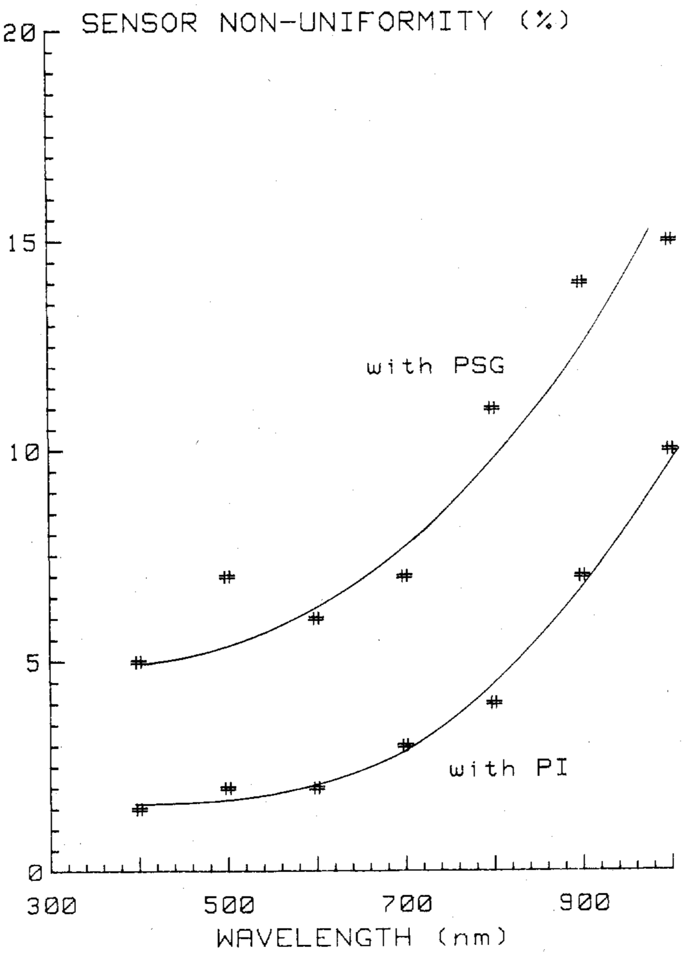

Fig. 1. Illustration of the sensor non-uniformity as a function of the wavelength of the incident light for two imagers: one with PSG, and one with PI as insulating layer between two aluminum levels. (The sensor non-uniformity is measured at 50% of a full charge packet and is expressed as a percentage, plus and minus, of a full charge packet.)

second metal layer defines the sensor geometry in the transverse direction. As a consequence, any irregular etching of the second aluminum layer leads to sensor area mismatching. The pattern in the light shield is more uniformly delineated if the topography of the surface is smoother. This is obtained by replacing PSG by PI. PI reduces not only the surface profile but it also generates a more uniform underground for the second metal layer when compared with the PSG-film. This results in a metal layer which is uniform in thickness, in contrast to PSG that can cause a metal shield thickness variation of about 30%. Wet etching of this metal film ends up in a window above the sensors, which has a notched side. This is not the case if the underlying surface gives rise to a uniform and shiny metal layer, as is present when a PI insulator is used.

For longer wavelengths, the sensor non-uniformity is primarily determined by the uniformity of the diffusion length of the minority carriers in the quasi-neutral bulk of the devices. For this reason, there is an enhanced non-uniformity in the sensor response once this effect is greater than the effect of sensor geometry mismatching. Because both effects, which give rise to sensor non-uniformities also are cumulative, CCD's with PI show a more uniform response for longer wavelengths also.

TABLE I. COMPARISON BETWEEN THE RESULTS OBTAINED FROM TWO DIFFERENT CCD-IMAGERS: ONE WITH PSG, ONE WITH PI, AS THE INSULATING LAYER BETWEEN TWO ALUMINUM LEVELS

Parameter	with PSG	with PI
D_{it} (/eV·cm^2)	$<10^{10}$	$<10^{10}$
t_s (sec)	1600	1700
V_T (V)	0.16	0.12
V_{TF} (V)	14.1	13.7
V_{BD} (V)	30.1	32.4

The results shown in Fig. 1 are measurements done on CCD-imager with an indium-tin-oxide storage-gate. The technology and the characteristics of this device are described elsewhere [5, 6]. The same observations, which are illustrated in Table I and Fig. 1, can be also made for CCD-imagers with a poly-silicon storage-gate or with photo-diodes which have their junctions diffused or implanted, as sensors. The same conclusions are always valid: all characteristics of the imagers remain unchanged, except for the non-uniformity of the sensors, which is decreased.

The reliability of the PI-insulated device is now being studied. Although it is difficult to already make conclusions about the lifetime of the CCD's, one can state that the first results are very promissing.

CONCLUSION

This paper has described the influence of a PI-insulator on the optical and electrical parameters of a CCD-imager when used instead of PSG in the classical CCD-process. Although the general CCD characteristics remain unaffected, the uniformity of the sensors is improved by a factor of 3 for short wavelengths. This result is independent of the sensor type used, because the decrease in sensor non-uniformity is related to the more uniform etching of the aluminum light shield.

ACKNOWLEDGMENT

The authors wish to thank V. Muls, who did the processing of the devices, and T. Van Nuland, who made the drive electronics for the imagers.

REFERENCES

[1] L. B. Rothmann, "Properties of thin polyimide films," *J. Electrochem. Soc.*, vol. 127, p. 2216–2220, 1980.
[2] S. J. Rhodes, "Multilayer metallization techniques for VLSI high speed bipolar circuits," *Semiconductor Intern.*, p. 65–70, March 1981.
[3] K. Mukai, et al., "Planar multilevel interconnection technology employing a polyimide," *IEEE J. Solid-State Circuits*, SC-13, p. 462–467, 1978.
[4] A. M. Wilson, "Polyimide insulators for multilevel interconnections," *Thin Solid Films*, vol. 83, p. 145–163, 1981.
[5] A. Theuwissen and G. Declerck, "ITO-technology for CCD-imagers," *Conf. Abstr.*, p. 216–217, presented at 10th ESSDERC/5th SSSDT, York, UK, Sept. 15–18, 1980.
[6] A. Theuwissen and G. Declerck, to be published.