A Design-analysis Flow Considering Mechanical Stability of Metal Masks for Organic CMOS Circuits

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Abstract—A design flow to analyze metal masks of organic transistors is proposed. Mechanical strength of the mask as well as electrical property is simultaneously accounted for to define design rules. Through numerical experiments using a ring oscillator circuit, an example design rule for the standard-cell-based organic CMOS circuits, which reflecting mechanical strength, is proposed for the first time.

1. Introduction

Organic semiconductors have been attracting an increasing attention because they can be processed on flexible plastic substrates using a relatively low temperature process \[1, 2\]. A set of metal masks, each of which serves as a stencil to paste conductive or semiconductive materials, is used to form the patterns of organic transistors. In general, layout design of semiconductor circuits is to compose such masks. Basically, there is no difference between the mask-layout design of organic transistors and silicon transistors, except that the former utilizes metal masks that serve as direct stencils to print patterns whereas the latter uses photomasks to develop photoresist on the wafer.

Special care needs to be taken when the masks are actually used. The accuracy of the alignment significantly influences on the feature size of the transistors. In the fabrication of organic CMOS circuits, the mask is aligned and then fixed by magnetic force, during which the minute metal-mask structure may be largely deformed. This enforces a new type of constraint in the design of metal masks in addition to the conventional rules, such as minimum wire width, minimum extension of gate beyond channel, etc. The masks must perfectly maintain their shape under the strong magnetic field.

Fig. 1 shows an example of the large deformation of the metal mask calculated by a computer aided engineering (CAE) tool \[3\]. The blue area represents larger displacement along z-axis due to the attractive force of the magnet. Due to the two long slits, the metal mask is bending along the magnetic field of a fixing magnet, which results in inaccuracy of the mask alignment and the device dimension. Thus far, there is no rule-checker program to evaluate the mechanical strength of the designed mask. This type of rules has been never required in silicon chip design, hence new rules that consider mechanical strength need to be developed.

In this paper, a design-analysis flow of metal masks for organic transistors is proposed, in which the mechanical strength as well as the electrical property are simultaneously considered for defining new design rules.
In order to simultaneously consider mechanical strength of the metal masks and electrical characteristics of the fabricated organic transistors, we propose a mechanical-electrical analysis flow, which is illustrated in Fig. 3. The mechanical design rules are verified using CAE tools. In addition, on the basis of quantitative analysis, design rules that balance the mechanical and electrical properties can be defined, i.e., tradeoff between mechanical strength of the mask and the electrical characteristics of the fabricated organic CMOS circuits are considered to avoid excess margin for the manufacturability.

3. Experimental Results

The deformation and the parasitic resistance of metal masks for nine-stage ring oscillator are evaluated by the proposed analysis flow. Fig. 4 shows the layout of the ring oscillator. In the experiment, the gap size of the stitching $W$ shown in Fig. 2(d) is changed. A fabrication process of organic devices is based on [2], assuming that the metal mask of SUS430 (Young's modulus=2.0 GPa, Poisson's ratio=0.3, relative magnetic permeability = 500) is fixed using a ferrite magnet (magnetic flux density=135.2 mWb/m$^2$) on the organic substrate. The length, width, and thickness of the metal mask are 18 mm, 14 mm, and 20 $\mu$m, respectively. The displacement under the magnetic force was simulated using a CAE tool [3]. Four sides of the metal mask are fixed in the simulation. For the calculation of the parasitic resistance, we use $R_{\text{MBG}} = 0.77 \Omega/cm$ as the sheet resistance of the MBG layer, which is obtained from the measurement. The sheet resistance of the PM layer, $R_{\text{PM}}$, is assumed to be twofold $R_{\text{MBG}}$. The lengths of the PM and MBG layers are modeled as depicted in Fig. 5. The total parasitic resistance was calculated as the sum of the resistances of the MBG and PM layers.

Fig. 6 summarizes the change of the maximum displacement of the MBG layer and parasitic resistance along the VDD/GND lines as functions of $W$. Note that $W = 0$ mm means VDD and GND are continuous in the MBG layer. Even a very small support of 100 $\mu$m made by the stitching gap is effective to reduce the mask deformation, but further increasing the gap size does not significantly reduce the maximum displacement. Potentially, “at least one stitch should be made for every standard logic cell” can become a mechanical rule in the design of organic CMOS logic circuits. Shown in Fig. 1 was the very large transformation of the mask due to the magnetic force when $W = 0$ mm. Fig. 7 shows the displacement when $W = 1.2$ mm. The center of the metal mask is supported by the stitching, improving the maximum displacement from 9.12 mm to 4.31 mm.

On the other hand, parasitic resistance linearly decreases as we increase the gap $W$. Through the proposed analysis, we found there exists a tradeoff between the mechanical strength of the mask and the electrical characteristics of the fabricated circuit as shown in Fig. 6. Our analysis flow is useful to effectively design and fabricate the standard-cell-based organic CMOS circuits.

4. Conclusion

An analysis flow of the metal mask for organic CMOS circuits useful to define design rules is proposed. Using a CAE tool, the displacement of metal masks is calculated and some important observation when designing a standard cell type logic cell has been drawn.

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References