Development of a New a-Si Photoreceptor Drum by DC Plasma CVD

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Abstract

We developed a new pulse DC plasma CVD layer deposition process for a-Si photoreceptor drums instead of the ordinary high frequency 13.56 MHz plasma process. This has made the layer deposition process speed 2 times faster, minimized by-product powder generation and improved the surface smoothness of the a-Si drum. Through these improvements, we realized production cost reduction. This makes it easier to offer small diameter a-Si drums for tandem color printers, where growth in demand is predicted.

Introduction

The a-Si drum is widely used, from compact size office printers to ultra high speed industrial printers, because of its high durability against abrasion. However, compared to the OPC drum, the production cost of the a-Si drum is higher because it requires a vacuum process. So we reconsidered the main layer deposition process from the beginning.

We changed the discharge method from ordinary 13.56 MHz to minus pulse DC. Then, by changing the position to apply discharge energy from the electrode to the drum substrate, we achieved more than 2 times higher layer deposition process speed. This discharge method also minimized the production of by-product PolySi powder and produced a higher hardness SiC surface layer than before.

Experiment and Discussion

Pulse Negative DC Plasma CVD

First, we explain about newly developed minus DC plasma CVD (hereinafter DCCVD). Figure 1 shows cross sections of the DCCVD and ordinary RFCVD processes. In the case of RFCVD, RF is applied on the surrounding electrode and the drum is grounded.

The big difference of DCCVD is that minus DC is applied on the drum substrate and the surrounding electrode is grounded. The drum substrate is isolated on both top and bottom and it rotates during the process. The surrounding electrode is grounded and works also as a gas introduction fixture. The discharge power is applied from a DC power supply through a cable, so construction is simplified. 33 KHz DC pulses are applied and controlled to 70% duty. The impedance matching equipment is no longer required.

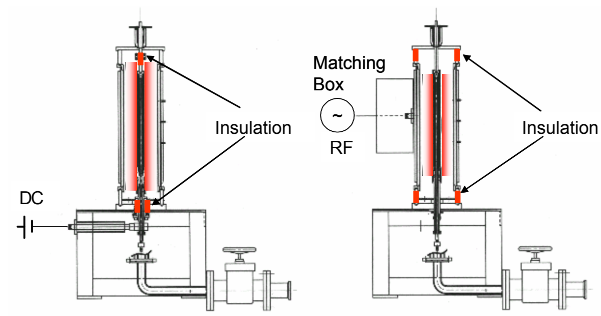

Figure 1. Cross Section of DCCVD and RFCVD Process.

Characteristics Comparison Between DCCVD and RFCVD

Table 1 shows summary of DCCVD and RFCVD comparison.

Table 1: Summary of DCCVD and RFCVD

	DC CVD	RF CVD
Substrate bias potential	Approximately 1,000V	Approximately 10V (Self-bias)
Deposition electrode	Concentrate on substrate	Both electrode substrate
Deposition efficiency of SiC film	Very high	Very low
Deposition efficiency of a-Si film	Slightly high	Standard
Electric noise	Nothing	Exists
Substrate charge up	Exists	Nothing
Ion damage	Exists	Nothing

The following items can be mentioned as distinguished merits of the DCCVD process.

1. Shorter layer deposition process time
2. Reduction of material gas
3. Reduction of greenhouse effect gas like CH_4
4. Minimize PolySi powder generation
5. Stabilize characteristics by high frequency noise-less process
6. Simplify CVD process equipment

On the other hand, the increase of carrier trap sites resulting from the charge up of substrate due to direct current and the deterioration of layer quality due to higher deposition process speed and ion attack is noted. But these are not big problems for the a-Si drum. We will explain about layer quality later.

a-Si Drum Layer Construction

Figure 2 shows the layer structure of an a-Si drum. Carrier blocking layer, photo sensitive layer and SiC surface protection layer are applied on an aluminum substrate. Layer thicknesses are 5um, 9um and 1um.

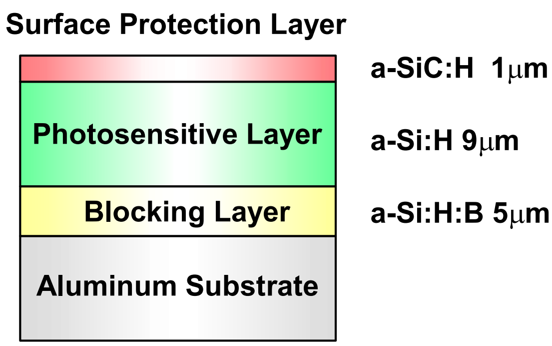

Figure 2. Layer construction of a-Si drum.

a-Si Photosensitive Layer by DCCVD

Layer quality deterioration by ion attack was expected. So to investigate layer quality, we checked G value and spin-density by ESR measurement method as shown in Table 2.

The G=2.0055 signal resulted from dangling bonds in a-Si. 1.4 times more dangling bonds are confirmed compared to an ordinary RFCVD layer. But we judged the value still fully satisfies the function of a photoconductor drum.

SiC Layer by DCCVD

We mentioned the hard surface protection SiC layer. When Si in the SiC surface protection layer of a-Si drum is oxidized, it absorbs moisture in a high humidity environment. This reduces surface resistance which causes the unclear image phenomena. To reduce oxide as much as possible, we reduce the Si content, leaving a surface of more than 90% C. So this can be called a C:H surface film. This has also been called C-rich.[2]

Table 2: ESR Measurement Result

	G	Spin Density (spins/cm3)
a-Si by DCCVD	2.0055	6.6E+15
a-Si by RFCVD	2.0055	4.7E+15

The SiC layer deposition is difficult by ordinary RF plasma CVD because of the C atoms in SiC. This can be understood when we consider C:H film construction. When CH_4 is used as source gas, the CH_3 radical becomes a precursor of the SiC film-deposition process. The main ions CH_5^+ and $C_2H_5^+$ in the CH_4 plasma attack the top layer by ion spattering and they push H atoms out to form dangling bonds. These become incorporation sites for CH_3 radicals and make the carbon film.[1]

From the above, incorporation sites can be produced with high efficiency and improved layer deposition process time by drawing cations to the substrate electrostatically. This makes the layer deposition speed faster. Therefore, faster SiC layer deposition process is realized by applying minus DC to the substrate.

On the other hand, in the RFCVD case, ions can hardly move due to the high frequency. So even a small amount of CH_4 source gas makes the layer deposition speed much slower.

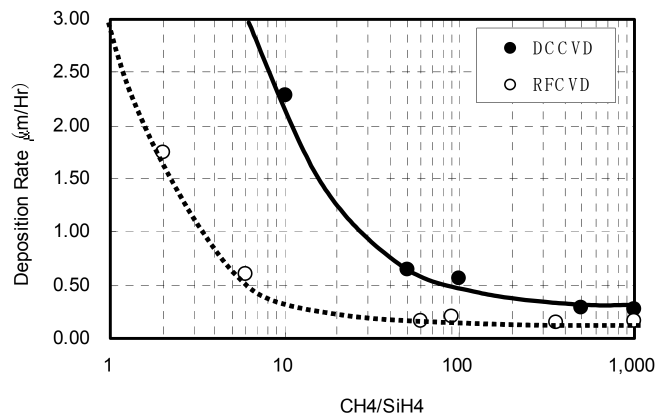

Figure 3. Relation between the CH4/SiH4 gas ratio and the layer deposition speed.

Figure 3 shows the relation between the CH_4/SiH_4 gas ratio and the layer deposition speed. Though layer deposition speeds for both DCCVD and RFCVD are reduced when the CH_4/SiH_4 ratio becomes higher, we can see that the DCCVD process is faster than RFCVD.

Figure 4 shows comparison of deposition process between RFCVD and DCCVD for a 1um thick SiC layer. DCCVD requires 1/3 deposition time compared to RFCVD. This means a 3 times faster layer deposition speed.

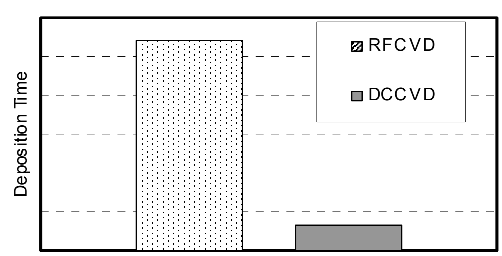

Figure 4. SiC layer deposition speed comparison between RFCVD and DCCVD.

Figure 5 shows the relation between C content in the SiC layer and hardness. In the case of RFCVD, hardness of SiC layer drastically drops when C amount becomes higher than 85%. On the other hand, it can be said that the drop of hardness from the DCCVD process is smaller.

Drastic improvement of durability is achieved because the surface C-rich layer has higher hardness when applied by DCCVD.

Figure 6 shows a comparison of actual printing abrasion amount between RFCVD and DCCVD. We can see that the DCCVD drum has 2.5 times higher durability against abrasion after printing with 100,000 sheets of A4 paper at 4% printing ratio.

Surface Property of a-Si Drum by DCCVD

Figure 7 is AFM images of a-Si drum surfaces of 1um area. The left side one is from RFCVD process; center from minus DCCVD and right from plus DCCVD. As you can see, the minus DCCVD surface is extremely smooth. We believe this is caused by the influence of etching from cation attack.

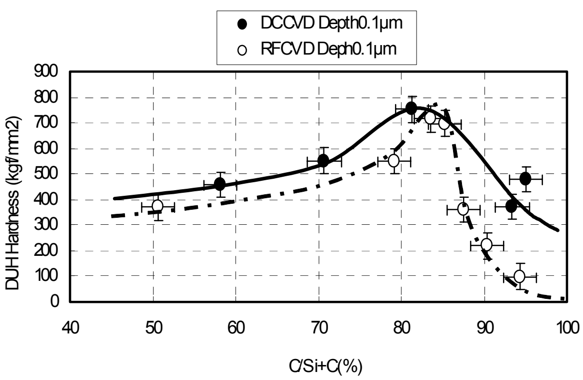

Figure 5. C composition ratio and hardness

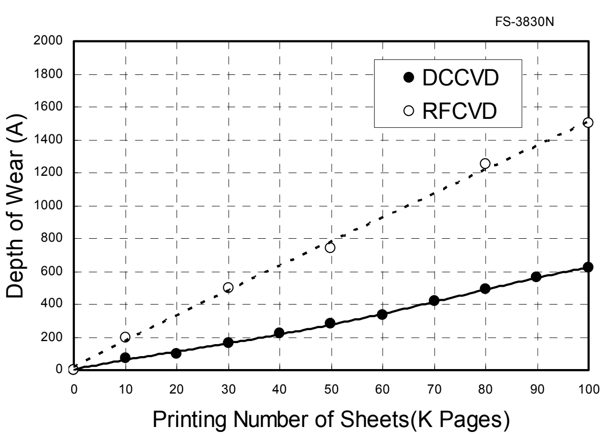

Figure 6. Abrasion amount comparison

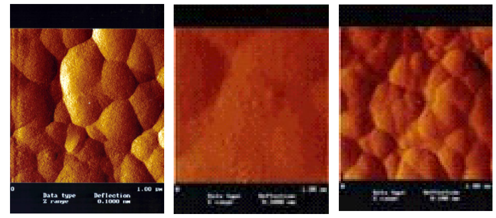

Figure 7. a-Si drum surface AFM images

To confirm this, we applied a layer with plus DC plasma. It is the right side image. As expected, the surface roughness from plus DC plasma is same as from ordinary RFCVD process because of smaller cation attacks.

SiH_x^+ and H_2^+ are included in SiH_4 plasma as plus ions. SiH_3 is included as minus ion. The concentration of SiH_3 ions is said to be 1/10 that of plus ions. We can understand this also from Dr. Tachibana's value.[3]

But when the a-Si drum surface is too smooth, its slip properties become worse. Then printer engines require more motor torque and more noise can be caused by minute vibrations. However, these issues can be counteracted easily by adjustment of printer process conditions.

On the other hand, there is merit to the DCCVD smooth surface. As we mentioned above, the long term print quality stability of a-Si drum depends on removing oxide and corona products by polishing its surface as a countermeasure to unclear image. Over its printing life, the drum surface becomes smooth because of mechanical polishing. This improves the efficiency of removal of oxide and corona products. It realizes higher deterrent effect. When the DCCVD process is used, a very smooth surface is achieved from the beginning. So there is higher polishing efficiency on new drums.

Deterrent Effect Against PolySi Powder During Layer Deposition Process

As we mentioned above, cations in plasma are attracted to the substrate and anions are repelled. So, there is the possibility that ions and neutral radicals hit with each other in plasma and this produces PolySi powder.

According to our measurement, it was confirmed that powder generated in DCCVD is reduced to less than 1/100 of that of the RFCVD process.

Generated powder in the layer deposition process causes not only defects on the layer but also decreases exhaust capability of the vacuum pump when it is drawn in it. This makes the pressure of the process uneven and affects the characteristics of the a-Si drum.

We can reduce generation of powder drastically by using the DCCVD process. At the same time, we not only improve a-Si drum quality but also production efficiency because of simplified chamber cleaning process after layer deposition.

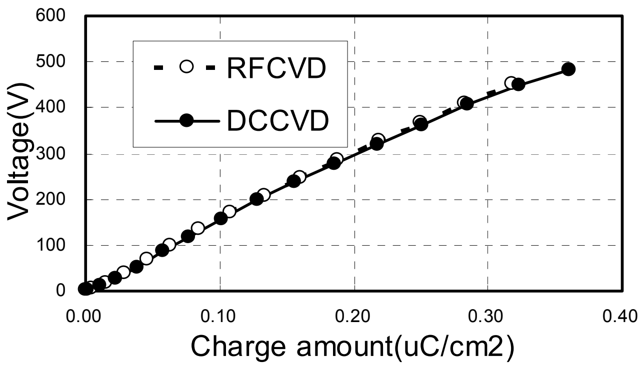

Figure 8. Q-V property

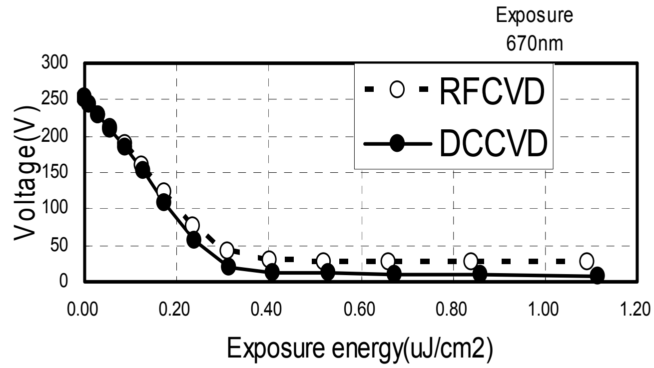

Figure 9. E-V property

Electrical Characteristics of DCCVD a-Si Drum

Figure 8 and 9 show Q-V and E-V properties. They show that characteristics similar to original RFCVD process a-Si drums are achieved. The E-V property is improved because full exposure of the drum now leaves almost no residual voltage.

Conclusion

We developed an a-Si drum with a faster layer deposition process and a higher hardness SiC surface protective layer by using the new DCCVD process.

This also improved production efficiency drastically by reducing PolySi powder generation during the layer deposition process.

From the above, we can lessen the price difference from OPC and make it easier to offer a-Si drums for color tandem printers.

References

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Author Biography

Akihiko Ikeda graduated from Nihon University, Dept. of Mechanical Engineering in 1985. In 1985, he joined KYOCERA Corporation in Shiga, Japan and has been engaged in development of an a-Si photoconductor drum, and deposition technology. He is now a Manager of Photoreceptor Production Department and Manager of Photoreceptor Development Section. Mr. Ikeda is a member of Imaging Society of Japan.