I. Introduction

High Oxygen permeability(1) is a prerequisite for contact lenses intended for extended wear, specifically for continuous day and night wear over days and weeks. The oxygen permeability of the ordinary hydrogel is limited to its water content, which cannot satisfy the oxygen permeability requirement for the extended wear application. Since the oxygen permeability of silicone elastomer is very high, silicone was formulated for contact lens application. However, due to hydrophobic surface and extreme surface tackiness, their tendency to adhere to the cornea became a serious drawback, which limited its practical application (2). Silicone hydrogel (3) was then developed to circumvent this problem.

Silicone hydrogel contains two phases; one is silicone phase, which is designed for the oxygen transport and another is hydrogel phase, which is for water transport including ions. The permeability of oxygen provided by the silicone phase is approximately 140 barrer (barrer: oxygen permeability unit in $10^{-11}$ cm$^3$ O$_2$ (STP) cm$^2$/cm$^2$ sec mmHg), which is higher than an estimate oxygen requirement for a healthy cornea metabolism. On the other hand, the ion transport through the hydrogel phase is found to be a prerequisite for on-eye lens movement, which prevents the lens adhesion to cornea.

In spite of the hydrogel incorporation to silicone polymer, the silicone phase dominates the surface characteristics of the silicone hydrogel lens. Thus, it is highly hydrophobic, tacky and lipophilic. The silicone hydrogel cannot be used without surface modification. The surface of silicone hydrogel in this application is modified to hydrophilic by a plasma polymer coating using a methane and air mixture. The plasma polymer coating also provides unique surface barrier property, which minimizes the imbibition nature of silicone polymer with the tear film components.

The contact lens performances of the silicone hydrogel with the methane plasma polymer coating are discussed in this paper.

II. Experimental

1) Silicone hydrogel contact lens

The silicone hydrogel used for this application is called Lotrafilcon A. The synthesis of Lotrafilcon A is illustrated in Figure-1.

A major part of the composition consists of a polyfluorosilicone macromer with 2-isocyanato ethyl methacrylate. The macromer contributes mainly to high oxygen permeability. N,N-dimethylacrylamide provides the hydrophilic phase of the system.

A summary of properties of Lotrafilcon A is shown in Table-1. The Lotrafilcon A contains a 24% of water and has a tensile modulus of approximately 1.2 MPa. The ion permeability coefficient is approximately 1 cm$^2$/sec and the oxygen permeability coefficient as

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Figure-1. Synthesis and formulation of a silicone hydrogel contact lens
is about 140 barrer, which is 6 times larger than that of a traditional hydrogel contact lens.

<table>
<thead>
<tr>
<th>Chemical structure</th>
<th>Fluoro silicone macromer copolymerized with TRIS and DMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (%)</td>
<td>24</td>
</tr>
<tr>
<td>Modulus (MPa)</td>
<td>1.2</td>
</tr>
<tr>
<td>Ion permeability</td>
<td>1.0</td>
</tr>
<tr>
<td>Oxygen permeability (Barrers)</td>
<td>140</td>
</tr>
</tbody>
</table>

Barrer : Oxygen permeability unit (1x10^-11 cm³O₂ (STP) cm⁻²/cm² sec mmHg)

2) Plasma polymer coating

Plasma polymer coating is performed using a gas mixture of methane and air under the influence of an electrical energy (15 kHz). A bell jar type reactor is used, which is equipped with a moving substrate system. The moving substrate system can ensure the coating uniformity on both sides of the contact lens. The plasma coating thickness measured on the silicone hydrogel contact lens is approximately 22 nm and the uniformity of the plasma coating coverage over the contact lens is confirmed by XPS and dye test(4). The contact lens wettability is significantly increased by the methane/air plasma polymer coating, obtaining a contact angle of 45 degree compared to 110 degree before the plasma coating.

III. Results & Discussions

A schematic diagram of a structure of silicone hydrogel is illustrated in Figure-2. It contains two phases, silicone and hydrogel phase in co-continuous morphology as illustrated. Because of the continuous structure of hydrogel phase, ion permeability can occur. The plasma polymer coating does not obstruct the ion permeability when it is fully hydrated. This is attributed to nanometer-scale loosening of the plasma polymer coating(5). The lens mobility on eye is closely related to the ion permeability of silicone hydrogel.

The plasma polymer coating provides unique surface barrier property, which minimizes the imbibition nature of the silicon hydrogel. The protein uptake by the silicone hydrogel contact lens is significantly reduced by the plasma polymer coating as shown in Figure -3. The protein deposition of a traditional hydrogel was approximately 1,000 µg for 7 days, while the corresponding value of the plasma polymer coated silicone hydrogel was only 0.5 µg for 29 days of continuous wear(6).

The silicone hydrogel contact lens with the plasma polymer coating is commercially available and already has been worn by over a half of a million people.

References:
3) P.C Nicolson & J.Vogt, Biomaterials, 22, 3273 (2001)