# Characterizations of PVDF-HFP Copolymer and the Model Coating[1] of Xience V™ Drug Eluting Stent by Synchrotron

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**Statement of Purpose:** PVDF-HFP - Poly(vinylidene fluoride-co-hexafluoropropylene) is used as the drug reservoir polymer in Abbott Laboratories' XIENCE V™ drug eluting stent (DES). PVDF and it copolymers are known as semi-crystalline polymorph polymers with several crystalline phases. Since morphological information of DES drug-polymer matrix such as the crystalline phases, percent of crystallinity, crystal size, size distribution, and drug distribution are among the factors influencing the drug release, the focuses of this research are the crystalline and microcrystalline domain of PVDF-HFP co-polymer, and especially drug/PVDF-HFP coatings used on Xience V. The results of these studies may provide a better understanding of the *in vivo* pharmacokinetics of Xience V and aid in the understanding of how manufacturing process conditions affect the coating morphology. The coating on the stent is no more than eight micrometer and the strut thickness of the stent is approximately 80 μm. Therefore, it has been a challenge to characterize the crystalline properties of Xience V drug/PVDF-HFP coating.

**Method:** Wide Angle X-ray Diffraction (WAX) and Small Angle X-ray Scattering (SAXS) experiments were conducted using synchrotron. These measurements were performed on the beamline X27C at the National Synchrotron Light Source, Brookhaven National Laboratory. The instrument detail can be found in the other references[2]. Novel model coatings to model Xience V were prepared by coating aluminum foil substrates by using Xience V formulation and process conditions. To enhance the signal, the thickness of the coating for systems 2 and 3 systems as mentioned below was increased to 50 μm. The experiments were carried out for three systems: 1. PVDF-HFP copolymer pellet as received, 2. PBMA primer and PVDF-HFP copolymer coatings, and 3. Model Xience V coating (PVDF-HFP Everolimus drug coat/PBMA primer/Aluminum). Differential Scanning Colorimeter (Mettler, DSC e823) and X-ray profile fitting were used to estimate the crystallinity.

**Results:** The WAX data showed that PVDF-HFP bulk copolymer, PVDF-HFP copolymer coating, and model Xience V coating contain α-crystalline phase with lamella structure. The diffraction patterns of three systems matched the X-ray diffractions of PVDF homopolymer [3].

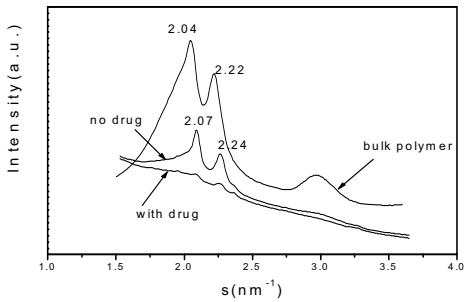


Figure 1. WAX comparison, two major diffraction patterns were corresponding to 020, 110 refractive surface of α-crystalline

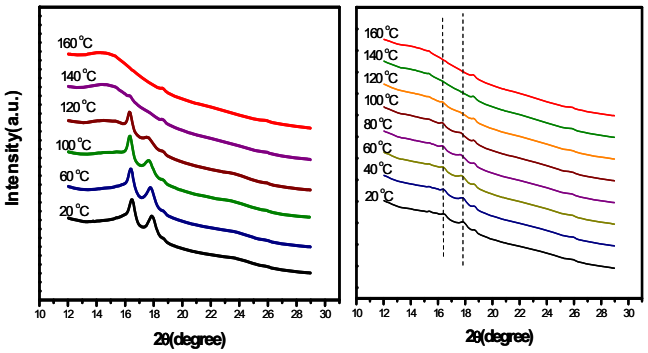


Figure 2. WAX as a function of temperature for model Xience V coating (left) and PVDF copolymer coating (right)

Compared with the pure polymer coating, the diffraction peaks of Model Xience V coating were less obvious, which indicates that it contain less crystalline phase. SAXS data demonstrated that bulk polymer PVDF-HFP contains micro-crystalline domains, which have a lamella structure: a crystalline layer and an amorphous layer. The thickness of the crystalline lamella is about 2 to 3 nm at room temperature. The size of lamella micro-domain changes as the crystal melts. However, for the polymer coating and model Xience V coating, SAXS showed no peak, which indicates no micro-phase (at least at nano-scale) for PVDF-HFP and Model Xience V coatings.

**Conclusion:** Synchrotron experiment demonstrated that bulk PVDF-HFP copolymer is a semi-crystalliline polymer with α-crystalline structure. SAXS data showed it melts at 40°C and completely melts at 160°C. WAX data showed the PVDF-HFP coating and Model Xience V coating contain similar α-phase crystalline structure as bulk PVDF coploymer. SAXS and WAX result showed bulk polymer, polymer coating, and model Xience V coating differ in 'macroscopic' domain. These differences could be caused by surface tension (thins films are influenced by the property of its surface) and process (spray coating) which confine the crystallization of polymer. The coatings contain very small and sparsely-dispersed crystals at the scale of the unit crystal structure. It is attributed to the presence of Everolimus, the model Xience V coating contains much less crystalline. The data demonstrated that Everolimus molecules are embedded in the amorphous polymer phase.

**References:**

1. There was a difference from Xience V coating that the model coatings were not ETO sterilized, and the Xience V stent was. Further study will be carried out.
2. Christian Burger, Hong-wen Zhou, Benjamin Chu, et al, Applied Crystallography, (2008). 41, 252-261.
3. Lovinger et al, Polymer, 1980, 21, 1317.