RECENT CONTRIBUTIONS TO THE USE OF POLYIMIDE IN THE FABRICATION OF ICF AND IFE TARGETS

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ABSTRACT

This paper discusses some recent contributions to the use of polyimide in the fabrication of targets for Inertial Confinement Fusion (ICF) and Inertial Fusion Energy (IFE). Polyimide has many desirable properties, including much higher strength and the ability to withstand much higher temperatures than similar polymer films. Recent research efforts have focused on the use of polyimide in a number of applications including gasbag targets, hohlraum windows, spherical target capsules, anti-convection baffles and various shaped membranes such as target capsule supports and cylindrical z-pinch targets where polyimide's advantages contribute to superior target performance. Also covered are the fabrication of thick-wall target capsules and the potential production of thin-wall spherical capsules by a fully automated process.

I. INTRODUCTION

The capability to produce polyimide in forms useful in the fabrication of ICF targets has been developed over the last ten years.[1] In particular, sub-micron thick polyimide films have found use in applications such as x-ray astronomy[2] as well as in the fabrication of so-called gasbag targets and the entrance windows for gas filled hohlraums that have been used extensively to produce ignition-scale conditions in experimental work related to ICF.[3,4,5] Hundreds have been built by Luxel. A photograph of a gasbag target is shown in Figure 1. The gasbag itself (not counting the aluminum washer) is 2.5 mm in diameter and the polyimide film is 3500Å thick. It supports a full atmosphere of differential gas pressure. Similarly, laser entrance windows for indirect drive hohlraums are made routinely. They also withstand a full atmosphere or more, depending on the fill gas. More recently, the use of thin film polyimide is being considered for use in Inertial Fusion Energy (IFE) targets.

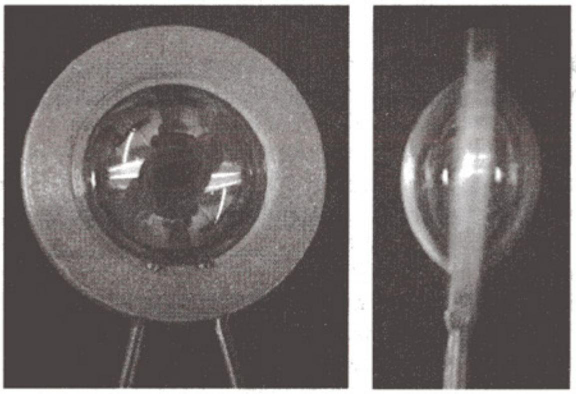

Figure 1. Gasbag target with 3500Å thick polyimide windows

II. THE ADVANTAGES OF USING POLYIMIDE

Polyimide includes a large class of aromatic polymers. Polymerizing a dianhydride and a diamine produces it. The particular polyimide that Luxel produces has a very high strength of approximately 3000 atmospheres as confirmed by standard mechanical tests of the bulk material as shown in Figure 2. The strength of sub-micron thick polyimide is measured by conducting bi-axial burst pressure tests.

Work directed at improving the strength of polyimide at cryogenic temperatures has produced excellent results in that by optimizing the cure cycle, the burst pressure of thin film polyimide has been increased by 36%. This has been accomplished without adversely affecting the strength or ductility of the material at other temperatures.

The strength advantages of polyimide have been considered for National Ignition Facility (NIF) targets[6] and many of the issues regarding target capsules for ICF experiments have been published.[7] References 1 & 6 also contain data comparing the strength of various polymers. See also papers on polyimide shell fabrication by Letts and Knight in this issue.

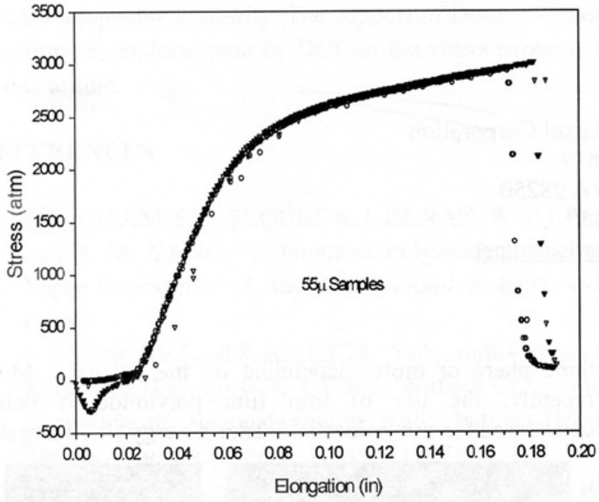

Figure 2. Stress vs. elongation for high strength polyimide

Recent attempts to produce the same polyimide by vapor deposition have produced some very interesting results, as shown in Figure 3. The burst pressure strength of the vapor deposited material is significantly less than the burst pressure strength of spin cast material at thicknesses above about 2000Å, but it is essentially the same as spin cast material for thicknesses of less than 2000Å. Perhaps the difference has to do with the orientation of the molecular chains. Other work on vapor-deposited polyimide is discussed in Ref. 8, 9, and 10.

Other advantages of polyimide in general include the ability to withstand temperatures in excess of 400° C, very high radiation resistance, and the blocking of ultraviolet radiation in the region from about 1500Å to about 3500Å.

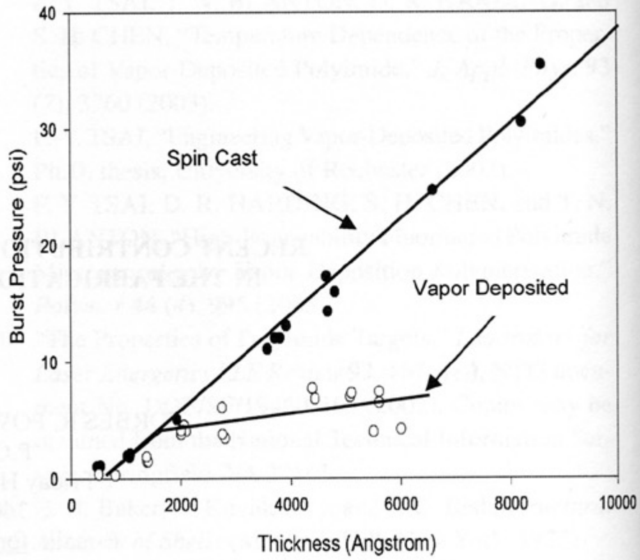

Figure 3. Burst pressure vs. film thickness for two types of polyimide

Polyimide can be formed in various ways to produce cylinders, hemispheres and more complex shapes, such as the so-called "tents" needed to support target capsules in NIF and IFE target capsules. An example of a cylindrical membrane fabricated for an experimental z-pinch target is shown in an enlarged photograph in Figure 4. The cylinder is 6mm in diameter, 16.5mm long and 25µm thick.

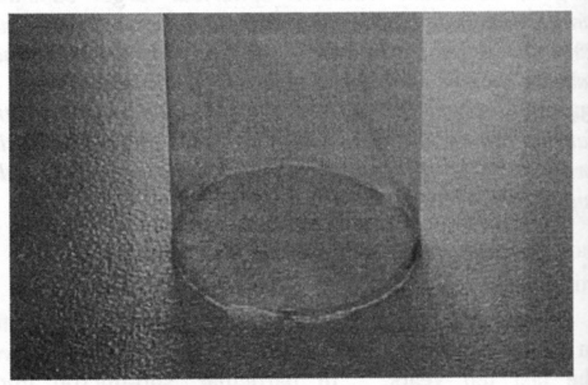

Figure 4. Experimental Z-pinch target cylindrical polyimide membrane

An artist's rendering of a shaped target capsule support currently being developed is shown in Figure 5. This type of target capsule support is envisioned for use in hohlraums for heavy-ion beam targets. It may also be used in NIF indirect drive targets.

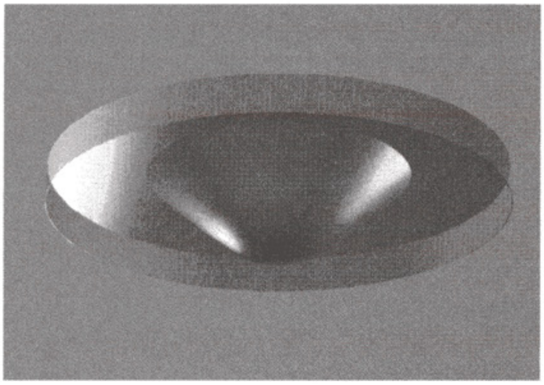

Figure 5. Complex shaped target capsule support

Thin films can be fabricated in thicknesses as small as 300Å or 30nm. An example of the use of thin film polyimide in a NIF indirect drive hohlraum being developed at LLNL is shown in the artist's illustration in Figure 6. (Illustration courtesy of LLNL.) Shown are two laser entrance hole windows, four anti-convection baffles and two target capsule supports.

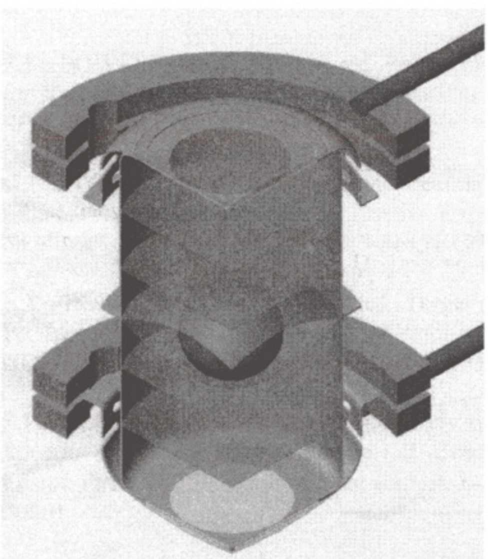

Figure 6. Conceptual NIF hohlraum showing LEH windows, baffles and capsule supports

III. THICK-WALL POLYIMIDE TARGET CAPSULES

With funding from LLNL, experimental thick-wall target capsules have been fabricated from solution-based polyimide. An image of one such capsule is shown in Figure 7. As shown, 70µm of cured high strength polyimide has been built up using an atomizer. The coating was applied to a thin walled CH mandrel, which is barely visible in the picture. The polyimide was cured using convective heating.

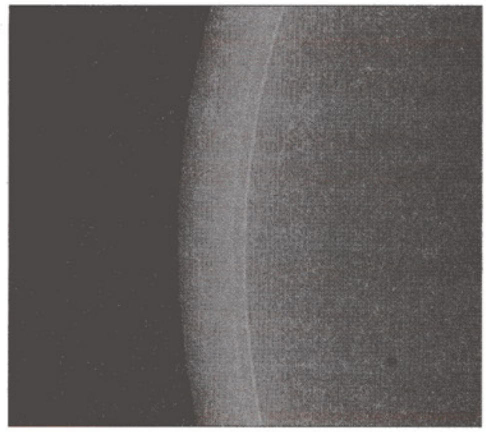

Figure 7. 70µm thick polyimide on a CH mandrel

Then, attempts were made to coat a stalk-mounted mandrel using ink jet technology. The advantage of the ink jet is that it can be computer driven to produce individual drops on demand. An example of a mandrel being coated by this method is shown in Figure 8. The advantage of this technique is that the coating process can be more precisely controlled to build up layers of the desired thickness. In these experiments, the individual layers were approximately 1µm in thickness. Attempts were made to use IR curing because the immidization can be accomplished much more rapidly than with convective heating. However, problems were encountered with buckling, probably because the heating was too rapid.

These techniques for fabricating target capsules with a solution based approach show promise, but more effort is needed to produce the desired results.

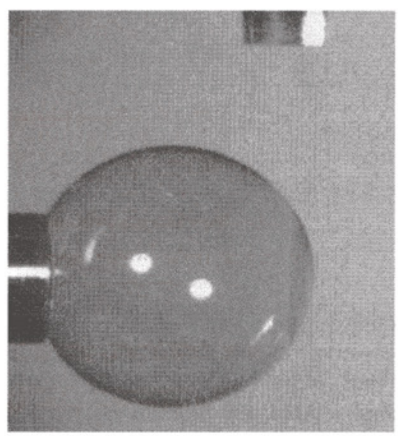

Figure 8. Stalk mounted target capsule coated with polyimide

IV. AUTOMATED FABRICATION OF THIN-WALL POLYIMIDE TARGET SHELLS

In February 2002, Luxel completed a Phase I SBIR contract with DOE to explore the feasibility of automating a method for fabricating thin-wall polyimide target capsules. This work successfully demonstrated the feasibility of such a process. Spherical bubbles of polyamic acid were blown, transferred to an acoustic levitator, and then cured to form thin-wall polyimide capsules. The process was accomplished under computer control and was fully automated such that there was no human intervention. A picture of a spherical capsule produced by this process is shown in Figure 9.

These first attempts produced spherical capsules with a Power Spectral Density (PSD) such as that shown in Figure 10.

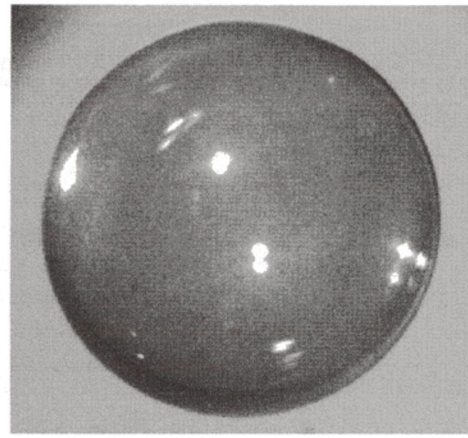

Figure 9. Thin shell polyimide capsule in acoustic levitation

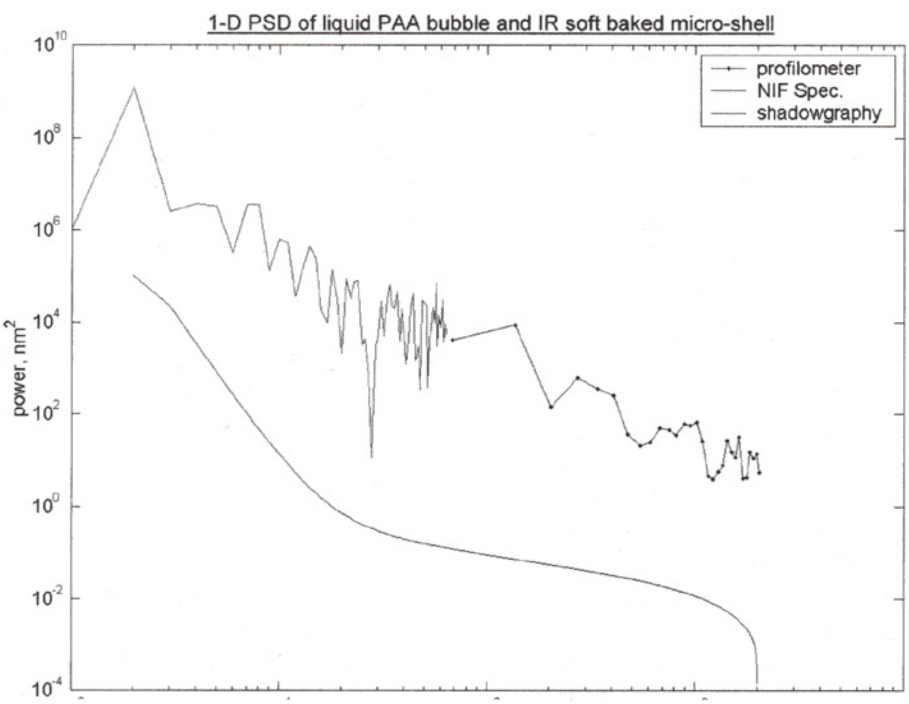

Figure 10. PSD for a polyimide target capsule made by an automated process

Obviously, significant improvement is needed to produce capsules of an acceptable quality, but it is believed that with further effort this could be accomplished. Also, the process could be fine tuned to increase yield, and it could be scaled to the production levels that will be required for IFE.

Also, other forms of levitation such as diamagnetic levitation should be investigated. An automated process could also be used to produce mandrels for thick wall target shells.

V. SUMMARY

The work presented here very briefly summarizes some of the progress that has been made at Luxel in the use of polyimide in fabricating various components for ICF and IFE targets, including recent work on producing spherical capsules. Some of the work, such as that involved in producing gasbag targets and windows for hohlraums, is straightforward and will continue in support of the NIF and other major programs. Some other aspects of the work, such as the automated production of spherical target capsules, is more problematic but should be pursued at some level because the payoff, particularly for IFE, could be huge.

ACKNOWLEDGEMENTS

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REFERENCES

1. F.R. POWELL and H.H. DE LOPEZ, "The Development of Ultrathin Polyimide for Laser Target and other Applications", *Fusion Technology*, **31**, 497 (1997)

2. F.R. POWELL et al., "Metalized Polyimide Filters for X-ray Astronomy and other Applications", *Proc., SPIE*, **3113**, 432 (1997)

3. G.F. STONE et al., "Fabrication and Testing of Gas-Filled Targets for Large-Scale Plasma Experiments on Nova", ICF Quarterly Report, **5-3**, 151 (1995)

4. L.V. POWERS et al., "Gas-Filled Target Designs Produce Ignition-Scale Plasma Conditions with NOVA", ICF Quarterly Report, **6-1**, 15 (1995)

5. S.H. GLENZER et al., "On the Accuracy of X-Ray Spectra Modeling of Dense Inertial Confinement Fusion Plasmas", ICF Semiannual Report, **1-1** (1999-2000)

6. J.J. SANCHEZ and S.A. LETTS, "Polyimide Capsules May Hold High Pressure DT Fuel Without Cryogenic Support for the National Ignition Facility Indirect Drive Targets", *Fusion Technology*, **31**, 491 (1997)

7. R.C. COOK, "An Overview of Capsule Issues for Current and Future ICF Experiments", *J. Moscow Phys. Soc.* **8**, 51 (1998)

8. S.A. LETTS, A.E. NISSEN, P.J. ORTHION et al., "Vapor-deposited Polyimide Ablators for NIF: Effects of Deposition Process Parameters and Solvent Vapor Smoothing on Capsule Surface Finish", *Fusion Technology*, **41**, 268 (2002)

9. E.L. ALFONSO, F.-Y. TSAI, S.-H. CHEN et al., "Fabrication of Polyimide Shells by Vapor Deposition for Use as ICF Targets", *Fusion Technology* **35**, 131 (1999)

10. F.-Y. TSAI, E.L. ALFONSO, D.R. HARDING et al., "Processing Vapour-Deposited Polyimide", *J. Phys. D: Appl. Phys.* **34**, 3011 (2001)