

Laser Sintering of Porous Aluminum Nitride for Environmental Applications

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Abstract: Aluminum nitride (AlN) is a high-bandgap, high-optical-refractive-index, electrical insulator with epsilon-near-zero behavior in the infrared atmospheric window. Towards binderless additive manufacturing of porous AlN, we demonstrate a 370% increase in hardness through laser sintering.

1. Introduction

Aluminium nitride (AlN) possesses desirable optical and optoelectronic properties particularly for ultraviolet light applications. From a mechanical engineering standpoint, AlN exhibits high thermal conductivity and low thermal expansion. Additionally, AlN is a phononic epsilon-near-zero material in the infrared atmospheric window [1], which indicates its potential for outdoor environmental radiative cooling applications [2]. These properties of porous AlN indicate favorable opportunities in novel manufacturing solar cells, photovoltaics, and electronic devices such as light-emitting diodes [3]. However, because and in spite of the thermal properties of AlN, largely its high material melting point of 2200° C [4, 5], it is difficult to develop inexpensive processes to fabricate porous AlN. Prior approaches to obtain porous AlN that overcome the high sintering temperatures required use of a slurry of binder compounds, which effectively enable hardening with lower sintering temperatures. These processes may be combined with flash sintering, which applies high heat, voltage, and laser radiation, and digital light processing. Such approaches may still require extensive sintering and pulsed laser deposition, typically performed in a vacuum or inert gas environment [5–8].

Here, we use a preliminary binderless technique to leverage the effects of laser treatment on a porous AlN slurry and to remove the need of a binder agent. High energy, ns-pulsed laser treatment increases both roughness and porosity in the form of burrs, grooves, and holes [9]. We demonstrate increased porosity and hardness of an AlN surface through laser sintering. FTIR and XRD spectra before and after processing indicate that the composition of the AlN does not change significantly as a result of treatment [Fig. 1].

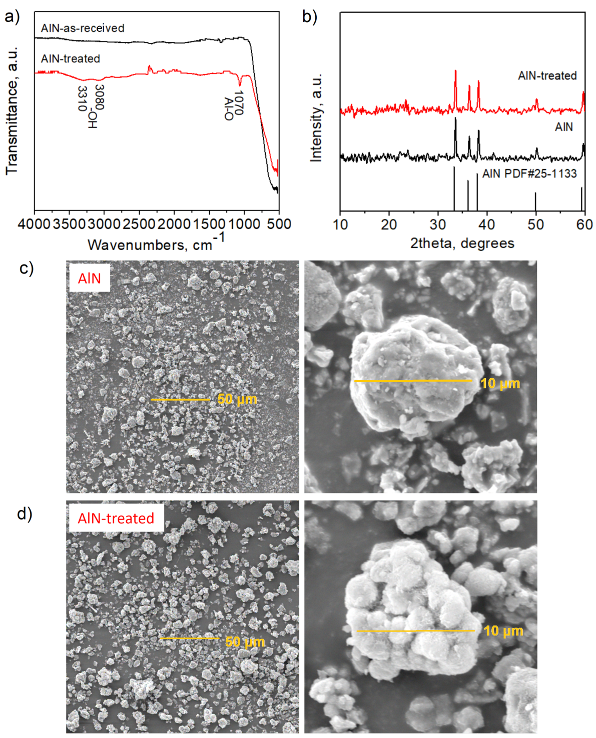

Fig. 1. a) FTIR b) XRD c-d) SEM of (un)treated AlN.

2. Results

Hardness testing is conducted on sections of a laser sintered sample and subjected to an increasing number of laser passes where the hatch spacing is held constant at 50 µm. The results of this test are shown in Fig. 2(A), which demonstrates that as the amount of laser passes on the surface is increased, the hardness of the surface also increases. From no laser sintering to five laser passes yields a hardness increase of 225%. Laser hardness performed using a conical indenter applied with a force of 22 N. Samples containing areas with a varying number of laser passes is sampled at three locations per section. The hatch spacing for each of these sections is held constant at 50 µm. As the number of passes of the laser increases, the hardness of the sample increases accordingly.

The laser sintering is carried out with varied parameters including hatch spacing and the number of passes with the laser. Fig. 2 demonstrates the effect of (B) no laser sintering, (C) 100 µm hatch spacing and (D) 10 µm hatch spacing. The image demonstrates the reduction in the radius of the crater left by the indenter during hardness testing, as well as an apparent increase in porosity. The hardness testing is performed with a modified Vicker's hardness test, where the indenter used is conical as opposed to the conventional pyramidal shape of standard Vicker's hardness test. To account for this change, the area used for the hardness calculation is changed to that of the conical indenter. From Fig. 2 (B) to (C) the hardness increases by 130% and from (B) to (D) the hardness increases by 370%. The results of the non-standard test are valid here since the measurement technique is held constant across the samples.

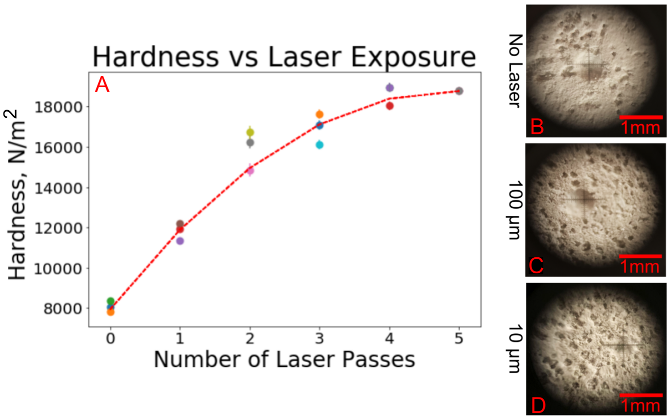

Fig. 2. (A) Increase in hardness of the surface as the laser flux is increased. AlN surface with (B) no laser exposure, (C) 100 µm hatch spacing and (D) 10 µm hatch spacing. The porosity of the sample also increases as the hatch spacing decreases.

3. Conclusion

We laser sinter porous AlN and increase its durability for potential environmental applications. A smaller hatch spacing contributes to increase the hardness of the surface of the material. We achieve a total increase in hardness of 370% from no laser to 10 µm. The hardness of the surface also increases significantly as the laser exposure increases, even though the temperature remains far the below the AlN melting point.

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