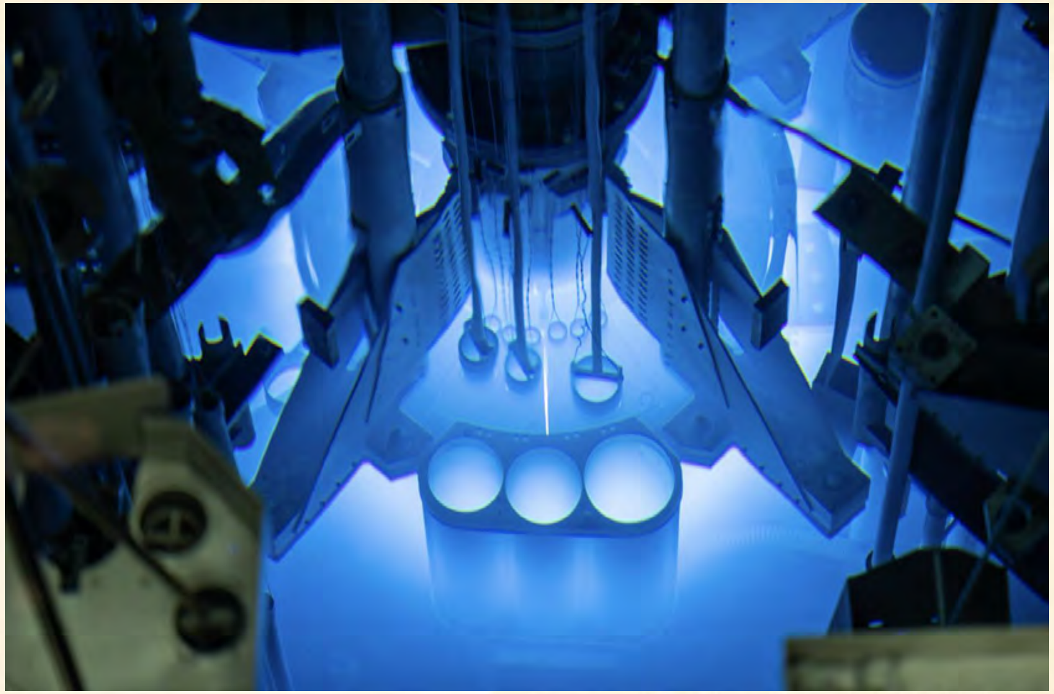
Neutron Transmutation Doping Control of Semiconductor Materials

John Gahl, EECS/MURR



Microelectronics

MURR and MU have a long history of using radiation to "dope" or modify silicon to make it useable in high power semiconductors.

This capability is now being brought to bear on Ultra Wide Bandgap (UWBG) materials, which are extremely difficult to dope in any other way.

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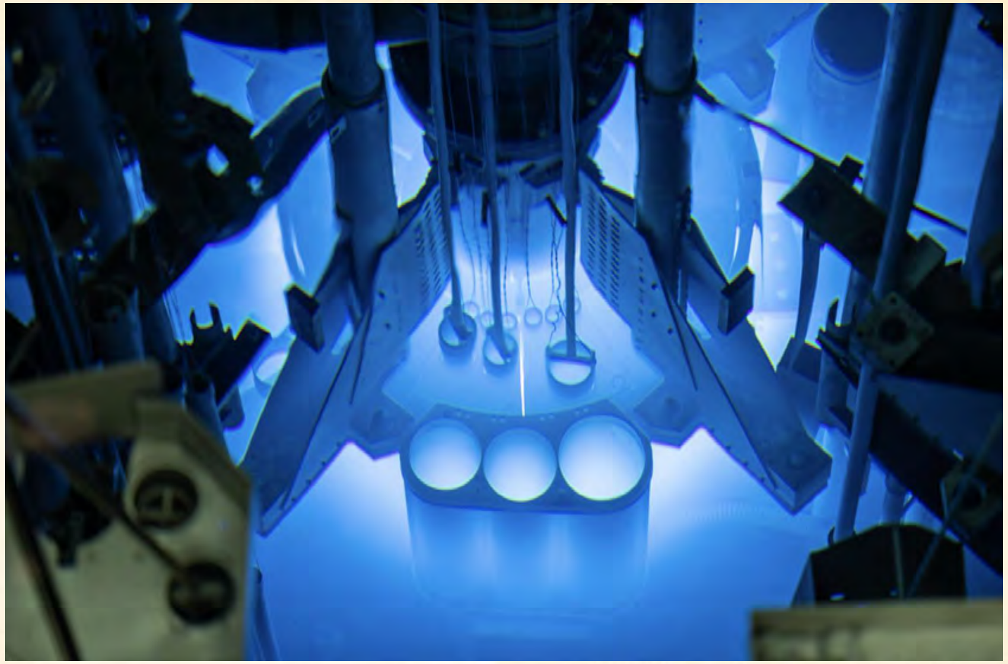

MURR has a decades long experience with transmutation doping of silicon started by Professor Jon Meese.

Neutrons captured by silicon cause decay to phosphorus, doping the silicon uniformly “n-type”.

Uniform doping allowed for high power operation. The process was successfully commercialized and research turned to new materials.

$^{30}\mathrm{Si}(\mathrm{n},\gamma)^{31}\mathrm{Si} \rightarrow {}^{31}\mathrm{P}+\beta^{-}\ (t_{1/2}=2.62h)$

(MEESE, J. M., COWAN, D. L., CHANDRASEKHAR, M., A review of transmutation doping in silicon, IEEE Trans. Nucl. Science NS-26 p. 4858 - 4867, 1979)

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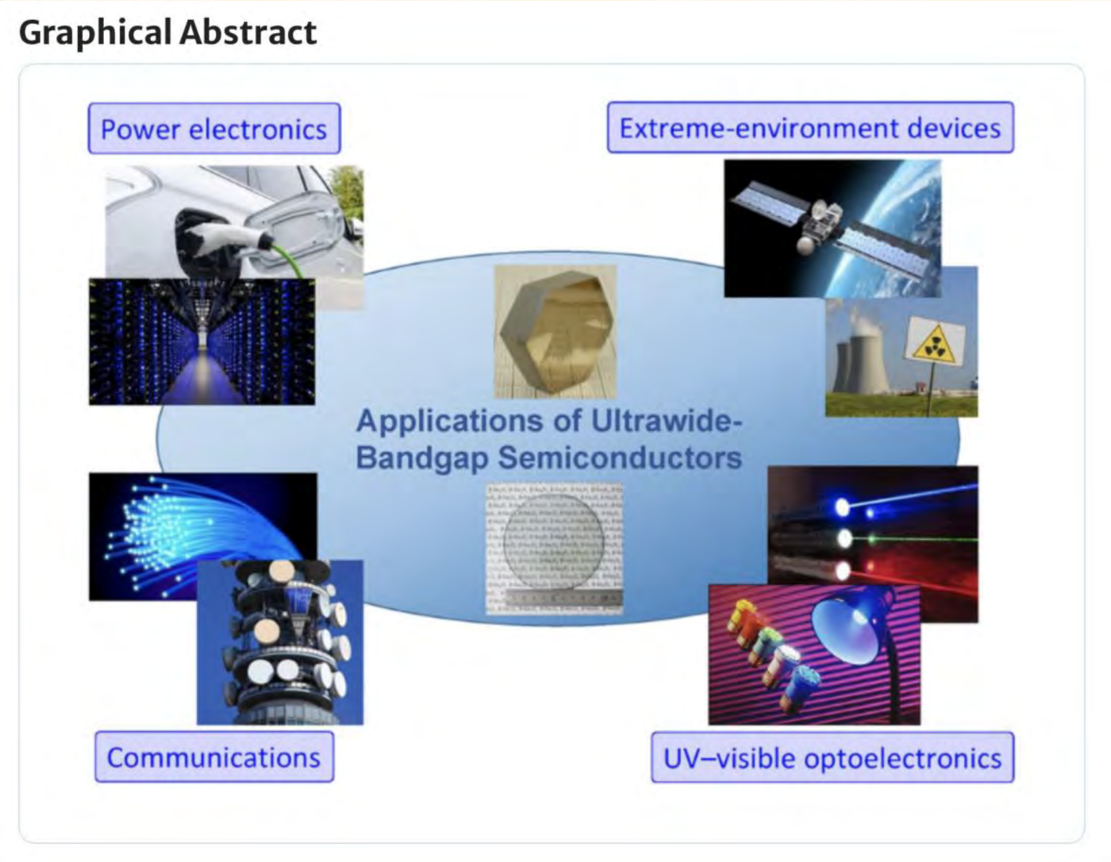

Microelectronics

Ultra Wide Bandgap (UWBG) materials can facilitate the creation of high-performance devices for a wide variety of applications.

These include but are not limited to; high power RF amplifiers and switches for radar and communication systems, high voltage switches for power electronics, and electronics for use in extreme environments.

Wong, M.H., Bierwagen, O., Kaplar, R.J. et al. Ultrawide-bandgap semiconductors: An overview. Journal of Materials Research ***36****, 4601–4615 (2021). https://doi.org/10.1557/s43578-021-00458-1*

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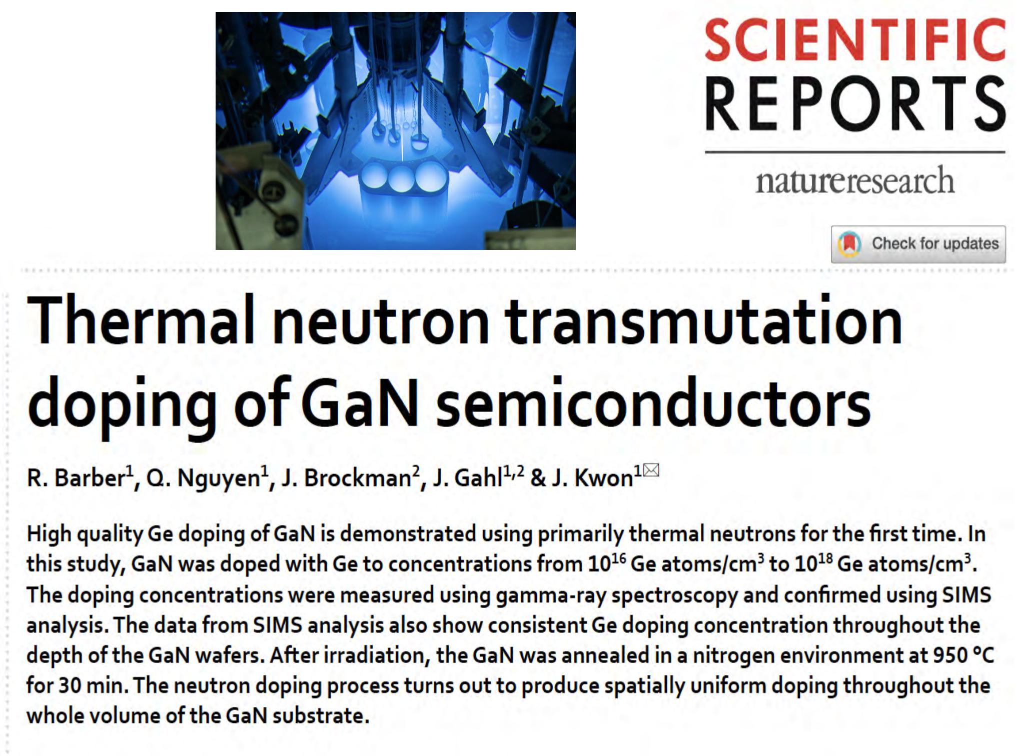

SCIENTIFIC REPORTS
natureresearch

Thermal neutron transmutation doping of GaN semiconductors

R. Barber[1], Q. Nguyen[1], J. Brockman[2], J. Gahl[1,2] & J. Kwon[1]✉

High quality Ge doping of GaN is demonstrated using primarily thermal neutrons for the first time. In this study, GaN was doped with Ge to concentrations from 10^{16} Ge atoms/cm^3 to 10^{18} Ge atoms/cm^3. The doping concentrations were measured using gamma-ray spectroscopy and confirmed using SIMS analysis. The data from SIMS analysis also show consistent Ge doping concentration throughout the depth of the GaN wafers. After irradiation, the GaN was annealed in a nitrogen environment at 950 °C for 30 min. The neutron doping process turns out to produce spatially uniform doping throughout the whole volume of the GaN substrate.

The wide band gap material GaN has been successfully transmutation doped, now emerging ultra-wide band gap material gallium oxide (Ga_2O_3) is being irradiated. Gamma spectroscopy suggests doping has been successful, four additional diagnostic techniques now being employed to verify.

$$^{69}\mathrm{Ga}(\mathrm{n},\gamma)\,^{70}Ga \rightarrow \,^{70}Ge+\beta^- \,(t_{1/2}=21min)$$

$$^{71}Ga(\mathrm{n},\gamma)\,^{72}Ga \rightarrow \,^{72}Ge+\beta^- \,(t_{1/2}=14.1h)$$

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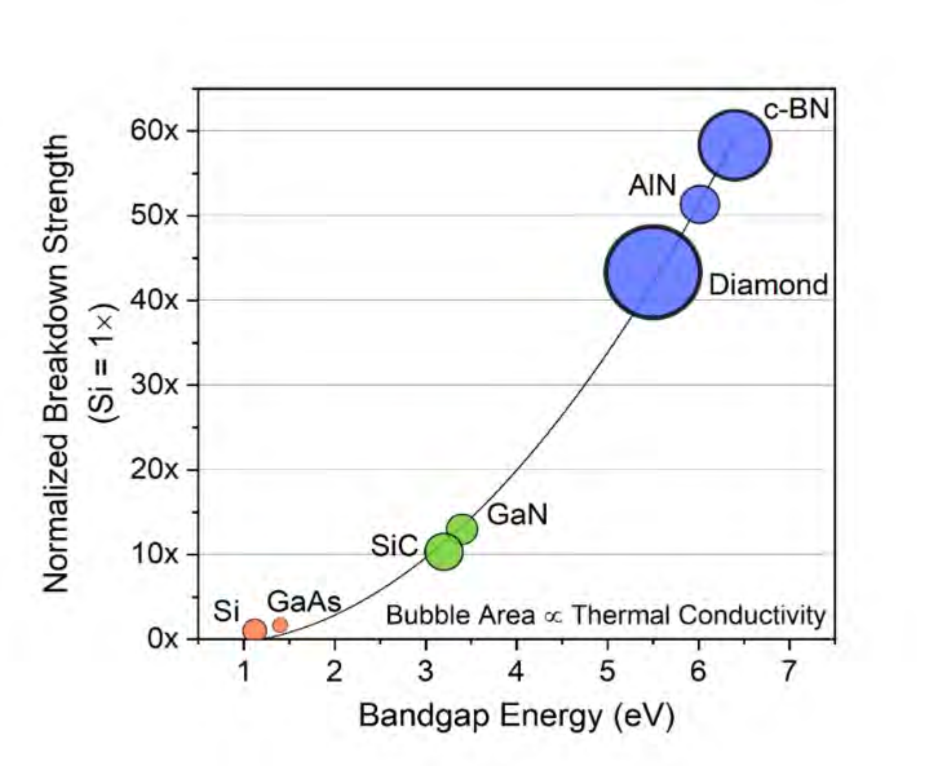

Microelectronics

Doping (incorporation of electrically active impurities that conduct current) is used to control the current conducting ability of semiconductors.

The large activation energy of typical UWBG dopants, material defects, and/or the formation of defect/dopant complexes, reduce the efficiency of incorporation of electrically active dopants.

For example, typical dopant incorporation efficiency for diamond is below 1% and for AlN is below 10% and is highly variable. The poor dopant incorporation efficiency results inunacceptably low material conductivity.

DARPA/ NRL

Ahmad, H., et al., "Realization of homojunction PN AlN diodes," J. Appl. Phys., vol. 131, 2022

Kato, H. et al., "N-type diamond growth by phosphorus doping on (0 0 1)-oriented surface," J. Phys. D, Vol. 40, 2007.

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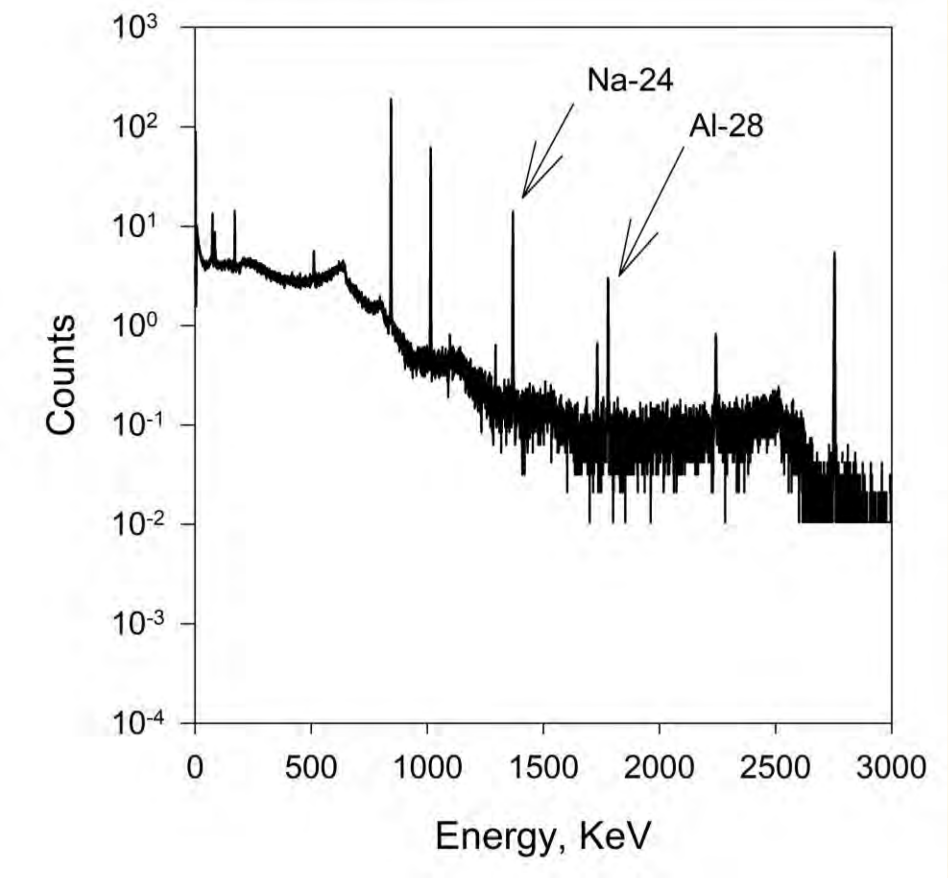

We proposed the first transmutation doping of an AlN substrate, utilizing lessons learned from our group's successful transmutation doping of GaN in MURR. There is no other known substrate doping technique for this emerging UWBG material.

Preliminary irradiation gamma spectrum of AlN, shown to the left, indicates a 1778 keV line, gamma decay product of activated Al decaying to stable Si, "n-type" doping AlN. This doping would facilitate true vertical conduction of AlN diodes.

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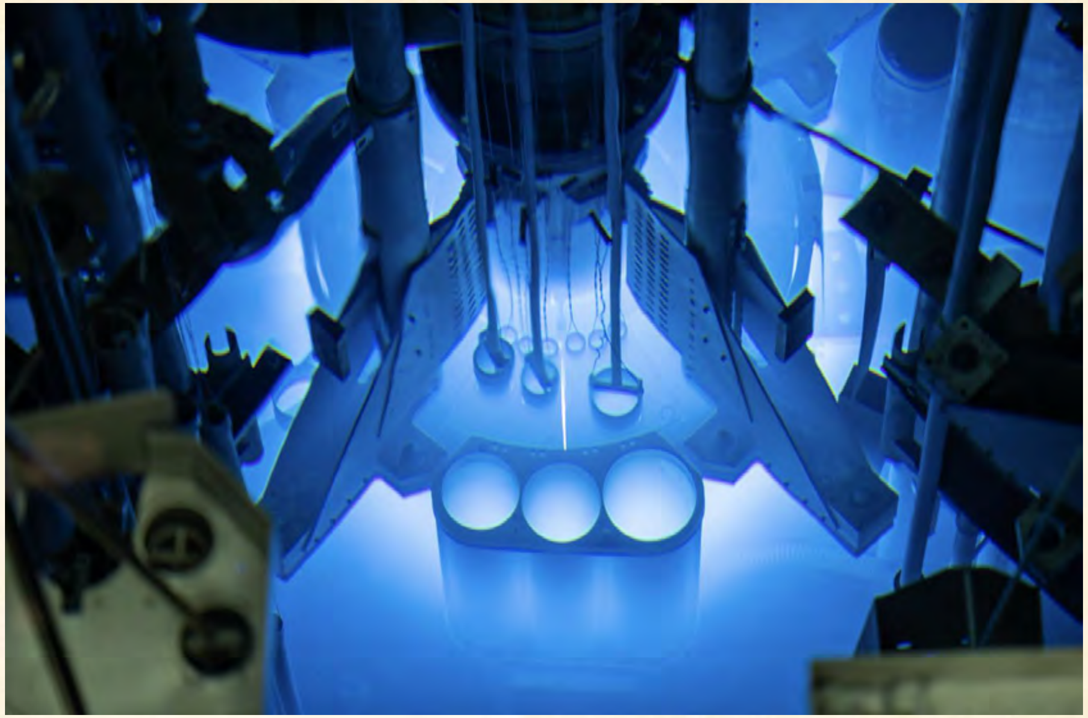

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Materials Under Extreme Conditions

Nuclear Engineered Materials

Neutron Irradiation Facilitating Material Performance

polymers

MDPI

Article

Polymeric Interlayer Strengthening with Boron Neutron Capture Radiation Treatment for Laminated Glass

Joseph C. Philipps [1], John M. Gahl [2], Hani A. Salim [1,*], John D. Brockman [3] and Michael C. Newberry [4]

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[2] Department of Electrical Engineering and Computer Science, MU Research Reactor, University of Missouri, Columbia, MO 65211, USA
[3] Department of Chemistry, University of Missouri, Columbia, MO 65211, USA
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* Correspondence: salimh@umsystem.edu

Polymers

Polymer interlayer materials are utilized in laminated glass systems to provide increased resilience from blast incidents.

The polymer chains within the interlayer material can benefit from material modifications that increase the crosslinking between adjacent chains.

One theorized method of targeted crosslinking is made possible through a boron neutron capture process.

This process utilizes neutron radiation that bombards boron material, thus producing emissions of highly energetic particles into the polymer.

Materials Under Extreme Conditions

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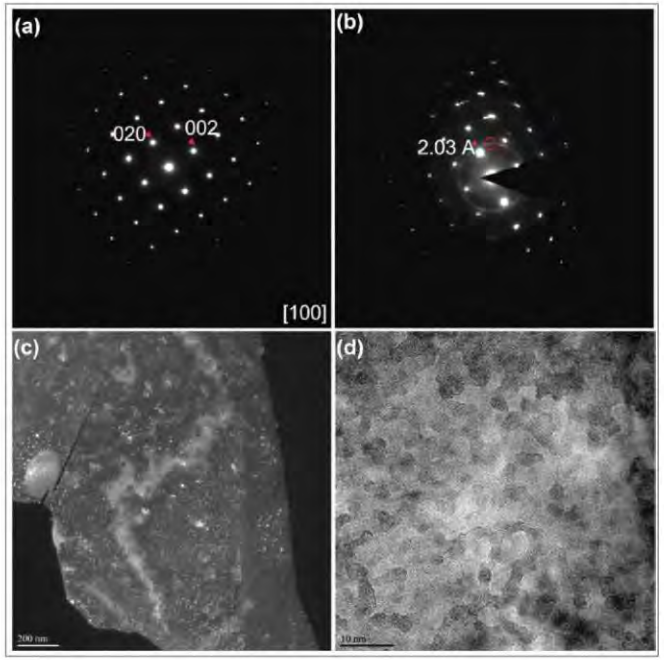

TEM bright and dark Field imaging

V. O'Donnell, X. He, T. Keya, G. Harvill, M. Andurkar, B.C. Prorok, S.M. Thompson, J. Gahl, Nuclear Technology, 210 (2024) 933-940.

Advanced Manufacturing, Structual Materials under Extreme Conditions

In this study, the performance of advanced (additive) alloy 625 was compared to the performance of wrought alloy 625 in a neutron (reactor) environment. The additive material outperformed the wrought.

In the figure to the left, a) is a diffraction pattern of wrought alloy 625 before irradiation, b) is post irradiation. Diffraction rings indicate precipitates forming.