

# Boron arsenide thermal management

**New substrate material reduces GaN HEMT hot-spot rise by 45% relative to diamond.**

**U**niversity of California Los Angeles (UCLA) and Irvine Materials Research Institute in the USA are proposing the use of boron arsenide (BAs) as a thermal substrate for power electronics devices such as gallium nitride (GaN) channel high electron-mobility transistors (HEMTs) [Joon Sang Kang et al, Nature Electronics, vol4, p416, 2021].

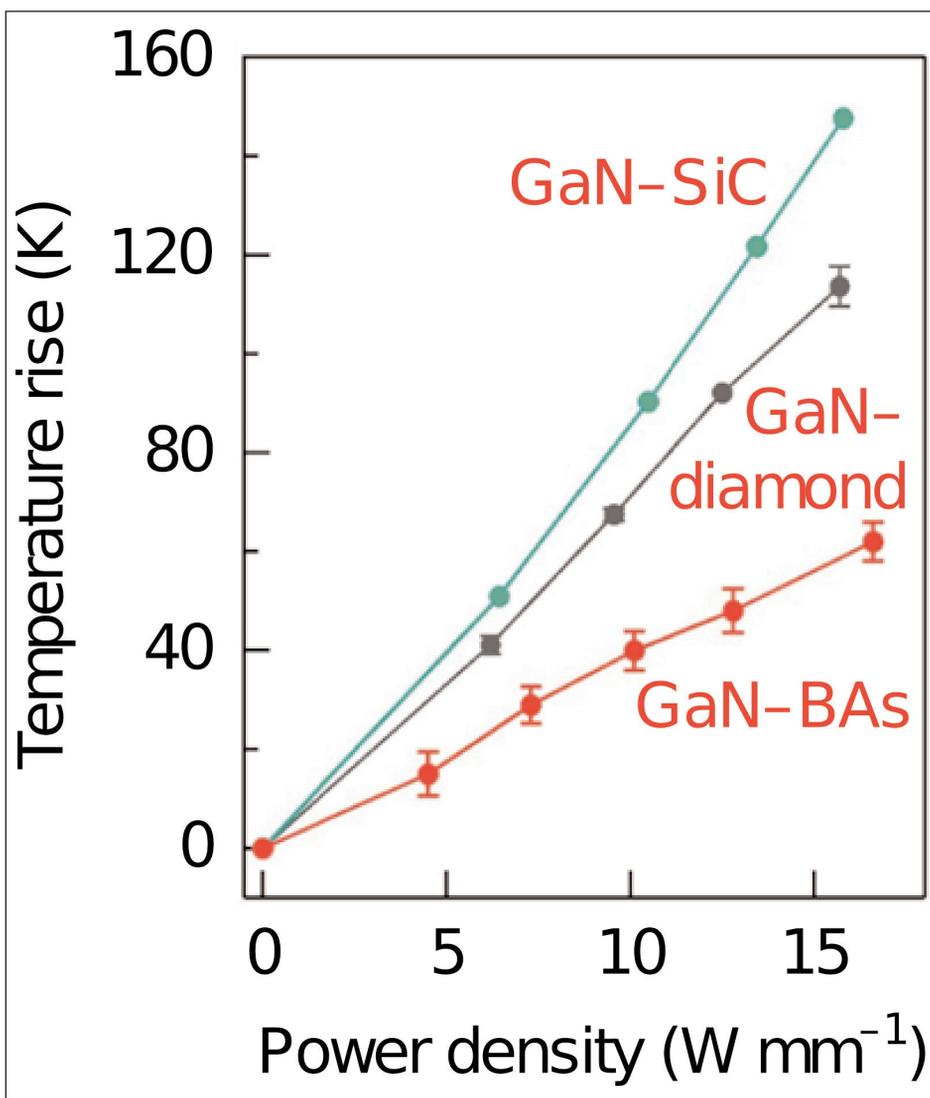
As power densities of electronics systems increase, the need to dissipate waste heat becomes more critical to avoid thermal failure. This needs a combination of high-thermal-conductivity materials and the ability for heat to cross material boundaries.

The GaN material/devices and BAs were bonded using thin aluminium oxide ( $\text{Al}_2\text{O}_3$ ) layers on both materials, applied using 10-cycle atomic layer deposition (ALD) at 473K. The surfaces were exposed to oxygen plasma before bonding to activate the interfaces. After bonding, the assemblies were annealed at 773K in vacuum.

The thermal stability of the process was confirmed by cycling the samples between room temperature and 600K, and the relevant properties measured. The researchers state: "All the samples were measured with consistent results and no appreciable degradation."

The HEMT devices were produced on silicon. The device layers were  $1\mu\text{m}$  GaN channel/buffer and 20nm AlGaIn barrier grown on  $\sim 1\mu\text{m}$  AlGaIn transition material to the silicon lattice. The  $100\mu\text{m}$ -width HEMTs were two-finger devices at  $34\mu\text{m}$  gate pitch. The devices were prepared for bonding to BAs with selective wet etching away of the silicon substrate and AlGaIn transition layers.

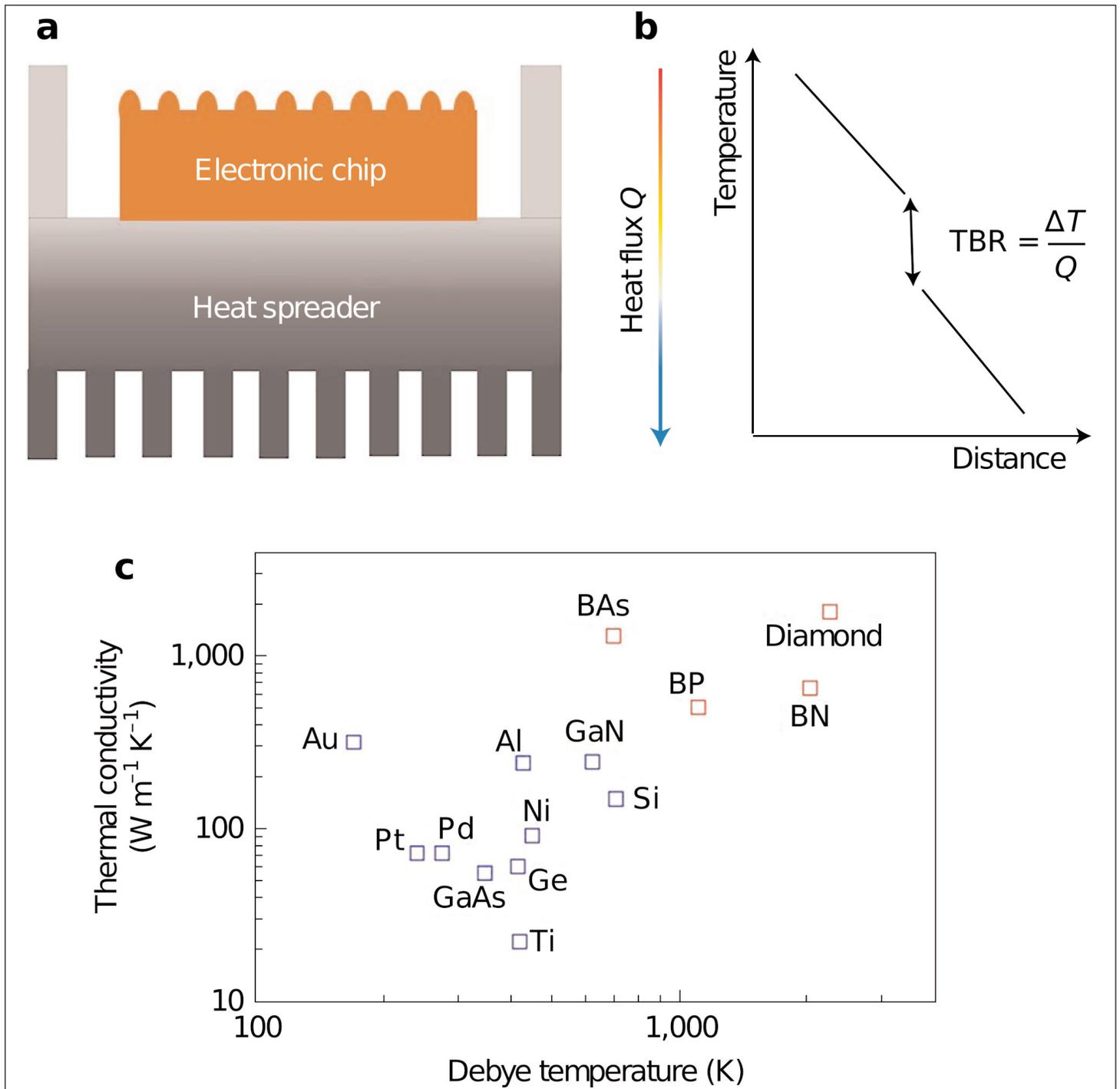
The HEMT on BAs showed improved thermal performance over similar devices on silicon carbide or diamond (Figure 1). At a power density  $\sim 15\text{W}/\text{mm}$ , the GaN-BAS HEMT suffered a hot-spot temperature rise of 60K,



**Figure 1. GaN temperature as function of power density, measured using Raman spectroscopy on drain side at lateral distance of  $0.5\mu\text{m}$  from the T-gate edge, for GaN transistors on BAs, diamond and SiC.**

much lower than the 110K for GaN-diamond and 140K for GaN-SiC.

The researchers attribute the improved performance of BAs to a combination of high thermal conductivity and low thermal boundary resistance (TBR), relative to the other materials. In fact, the thermal conductivity of BAs is  $\sim 1300\text{W}/\text{m-K}$ , while diamond's is  $\sim 2200\text{W}/\text{m-K}$ . The value for SiC is  $\sim 400\text{W}/\text{m-K}$ . The thermal boundary conductance (reciprocal of TBR) of GaN/BAs was measured using time-domain thermoreflectance,



**Figure 2. a, Schematic illustrating heat dissipation and thermal boundary resistance (TBR) at interfaces in microchip packaging. b,  $TBR = \Delta T/Q$ , where  $\Delta T$  and  $Q$  are temperature drop and heat flux across interface, respectively. c, Room-temperature thermal conductivities and Debye temperatures of representative metals, semiconductors and high-thermal-conductivity materials.**

giving a value of  $\sim 250 MW/m^2 \cdot K$  (about eight times higher than that of GaN/diamond). The researchers estimate that around 35% of the thermal resistance can be attributed to the oxide bonding layers.

The team believes that the lower thermal boundary resistance of GaN/BAs over GaN/diamond can be attributed to a better overlap between the properties of the quantized lattice vibrations (phonons) in GaN/BAs. At a simple level, the Debye temperature, derived from the linear spectrum model for specific

heat at low temperature, for BAs is much closer to that of GaN (and other common electronic materials) than diamond (Figure 2). The paper details more complicated theoretical work down to the atomic level, aimed at backing up the team's belief. In particular, a better overlap of the phonon spectra reduces the tendency for phonons generated in GaN to be reflected back at the boundary with BAs, reducing the TBR. ■

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