Why GaAs Offer Better Noise Figure Performance than Silicon Transistors

Gallium arsenide (GaAs) transistors offer better noise figure performance than silicon transistors, due to several material influences which include:

1. High electron mobility
2. Low intrinsic carrier concentration
3. Semi-insulating substrate

Let's examine these in greater detail.

1. Higher Electron Mobility

Electron mobility is a measure of how fast electrons move through a semiconductor material when excited by way of an electric field. Gallium arsenide (GaAs) has a particularly high electron mobility over its Silicon competitor (up to 6x greater) due to several distinct advantages. GaAs has a lower electron effective mass which allows electrons to accelerate at a much higher speed through both the material and electric field, which means they spend less time exposed to these "noisy regions" and are less likely to be influenced by its side effects.

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Gallium arsenide is also adirect bandgap semiconductor over its silicon competitor which is an Indirect Bandgap semiconductor. With a Direct Bandgap advantage, electrons enter and then move in the conduction band without a loss of energy which boosts mobility. Silicon on the other hand requires additional energy to move in the conduction band which impedes free electron flow and lowers mobility (Higher Noise).

2. Low Intrinsic Carrier Concentration

Gallium arsenide offers a smaller band gap over its Silicon competitor, thus requires less thermal energy to move an electron from the valence band to the conduction band.

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This lower energy requirement for Gallium arsenide electrons, means that random thermal vibrations (temps above cold) create a much larger number of electron-hole pairs compared to a material with a larger band-gap like Silicon.

This process of Silicon electrons being thermally excited and then recombining with holes creates an unstable and constantly fluctuating number of carriers. This unstable and constantly changing population is and of itself electrical noise. A higher population of carriers leads to an inconsistent and greater current instability, and thus higher noise for the silicon transistor.

3. Semi-insulating Substrate

Gallium arsenide has a low parasitic capacitance compared to silicon. This coupling minimizes noise which would normally travel from the transistor to other parts of the circuit. Silicon on the other hand has a higher parasitic capacitance over Gallium arsenide which offers the opposite effect, higher capacitance equals higher noise figure. Gallium arsenide is by nature a semi-insulating substrate. GaAs substrates lower capacitance to ground, thus lower noise figure.

GaAs Derivatives

Derivatives of a pure gallium arsenide structure include high electron mobility transistors (HEMTs) which include a blend of Gallium arsenide and aluminum gallium arsenide to channel electron movement into a further confined narrow layer, which by design improves electron flow, reduces electron scattering and thus improves electron mobility.

A second generation of GaAs derivatives is a Pseudomorphic High Electron Mobility Transistor (pHEMT) which uses a blended layer of gallium arsenide and Indium Gallium Arsenide (InGaAs) to achieve an even higher electron mobility performance. The InGaAs layer is grown on to the GaAs substrate but doesn't perfectly match the adjacent lattice. This results in a higher energy "barrier" between the channel and the donor layer. That higher barrier yields improved electron confinement and electron channeling which restricts electron movement to a much more tightly controlled channel this lowering electron scattering, fewer collisions and this lower thermal noise over HEMTs and traditional GaAs solutions.