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Tutorial_3: Microwave Diagnostics for Fusion Reactors

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Microwave diagnostics are particularly important in that they do not, in general, perturb the plasma being measured, have relatively modest access requirements, and excellent spatial and temporal resolution. Fundamental measurements include: electron temperature (ECE radiometry), electron density (interferometry, polarimetry, and reflectometry), thermal, energetic, fuel, ash, and impurity ion distributions (ion cyclotron emission and collective Thomson scattering), fluctuations and flows (ECE-Imaging and microwave imaging reflectometry(MIR); Doppler, high-k, and cross-polarization scattering). In this tutorial, we describe the basic principles of a number of microwave diagnostics. Although the basic principles may be understood through reference to the cold plasma permittivity, the case of burning plasmas requires a treatment that encompasses thermal plasmas, non-thermal distributions, and relativistic effects.
In implementing microwave diagnostics on reactor plasmas, there is a slight increase in required operating frequencies mandating some technology developments1. However, there are considerably more serious issues raised by the harsh radiation environment. ITER is the first magnetic confinement fusion machine to be able to produce net fusion power and will generate radiation levels, i.e., neutrons and gamma rays, that are orders of magnitude higher than present-day experimental machines. There is thus a need to develop electronics with higher performance and capability, as well as the robustness to survive the hostile burning plasma environment. Major improvements can be realized by employing wide-bandgap materials, such as gallium nitride (GaN), which has a bandgap of 3.39 eV versus 1.43 and 1.11 for GaAs and Si, respectively. GaN semiconductor devices have been shown to handle high power, exhibit high breakdown voltages and low noise beyond 200 GHz. In addition, we describe recent activity in the development of ultra-miniature vacuum devices fabricated using solid-state technology which are also well suited to the harsh, reactor environment and which can provide the required power for active microwave probing diagnostics.
Another recent advance is the so-called "System-on-Chip"millimeter wave integrated circuit technology, where complete receivers and transmitters are fabricated on an advanced substrate integrated with high-reliability circuit protection and packaging. This allows one to optimize custom solutions that can be fabricated in bulk quantities at a fraction of today's cost. The small size of the resultant components greatly simplifies the shielding. Advanced optical designs reduce the port access requirements and are key to

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