The growth of CdTe thin film solar cell devices by close spaced sublimation (CSS) was systematically investigated. CdTe thin films were deposited onto CdS coated FTO (fluorine-doped tin oxide) substrates with varying substrate temperature (260 ... 475°C) under various pressures of nitrogen (1.8 × 10⁻³ mbar, 6.7 × 10⁻² mbar, 2.0 × 10⁻¹ mbar). The microstructure of the films was examined before and after activation treatment with a high-resolution field emission scanning electron microscope (FE-SEM) on ion beam prepared cross sections. The substrate temperature was continuously measured during the CdTe deposition. Therefore it is possible to define a temperature region in which compact CdTe layers could be deposited. In contrast, little influence of the chamber pressure on the grain size could be observed.

EXPERIMENTAL
A series of CdTe thin film solar cell devices with following device structure CdTe/CdS/FTO were grown onto CdS/FTO substrates at different substrate temperatures during deposition to different temperatures in a process. Substrates were heated up prior to deposition to different temperatures in the range 260 ... 475°C and then transferred above the evaporation source. For low substrate temperatures an increase of temperature up to 100 K during CdTe deposition is observed (see Tab. 1). Table 1 gives an overview of the varied deposition parameters including measured substrate temperatures during deposition. Deposition of CdTe was carried out under different pressures of nitrogen (1.8 × 10⁻³ mbar, 6.7 × 10⁻² mbar, 2.0 × 10⁻¹ mbar). The growth rate of CdTe was constant (~ 5 μm/min) for all depositions that means the sublimation temperature of the CdTe source had to be adjusted to compensate the loss in growth rate by increasing chamber pressures. Following CdTe deposition the activation treatment was performed by wetting the samples with drops of CdCl₂ dissolved in methanol and annealing in air at 410°C for 25 min in a muffle furnace. All devices were etched for 15 s in nitric-phosphoric (NP) acid etch. The activation treatment was not optimized for the specific as deposited CdTe microstructure. Immediately after etching the samples were transferred to a sputter furnace. All devices were annealed in air at 410°C for 20 min. The resulting microstructure was analyzed by cross sections cut with a diamond saw and etched for 15 s in nitric-phosphoric acid. All devices were cleaned with methanol and followed by an isopropanol wash before insitu ion beam polishing. The SEM micrographs of the CdTe thin film solar cell devices were prepared by ion beam polishing.

RESULTS
The microstructure of all samples was characterized by SEM investigation of the cross section before and after the activation treatment. A high-resolution field emission scanning electron microscope SU8000 by Hitachi (FE-SEM) was used to examine the microstructural changes by activation treatment. Cross sections of the CdTe thin film solar cell devices were prepared by ion beam polishing.

SUMMARY
The deposition parameters of closed space sublimation CdTe thin films were systematically varied and the resulting microstructure was studied on ion beam polished cross sections. Strong influence of the substrate temperature on the grain size and morphology could be observed. Deposition at low substrate temperatures result in small columnar grain morphologies. An increase in substrate temperature increases the diameter of the columnar grains until a certain substrate temperature there the columnar growth morphology is lost and grain sizes of 1.5 μm could be achieved.

CdTe thin films deposited at lower substrate temperature show a high degree of porosity between the columnar grains which is still present after activation treatment. Rising the chamber pressure leads to an increase in porosity also in films deposited at high substrate temperatures around 500°C. Anyway the continuous temperature measurement during the CdTe deposition indicates a temperature region around 320 ... 360°C visible in the SEM cross sections where the CdTe thin films show almost no porosity and good solar cell efficiencies could be expected.